



US009449621B1

(12) **United States Patent**  
**Mauri et al.**

(10) **Patent No.:** **US 9,449,621 B1**  
(45) **Date of Patent:** **\*Sep. 20, 2016**

(54) **DUAL FREE LAYER MAGNETIC READER  
HAVING A REAR BIAS STRUCTURE  
HAVING A HIGH ASPECT RATIO**

(71) Applicant: **Western Digital (Fremont), LLC**,  
Fremont, CA (US)

(72) Inventors: **Daniele Mauri**, San Jose, CA (US);  
**Savas Gider**, San Jose, CA (US); **Hui  
Zhao**, Fremont, CA (US); **Ming Mao**,  
Dublin, CA (US)

(73) Assignee: **WESTERN DIGITAL (FREMONT),  
LLC**, Fremont, CA (US)

(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 0 days.

This patent is subject to a terminal dis-  
claimer.

(21) Appl. No.: **14/674,899**

(22) Filed: **Mar. 31, 2015**

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 14/670,340,  
filed on Mar. 26, 2015.

(51) **Int. Cl.**  
**G11B 5/39** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **G11B 5/3932** (2013.01); **G11B 5/3951**  
(2013.01)

(58) **Field of Classification Search**  
CPC ..... G11B 5/39; G11B 5/3903; G11B 5/3906;  
G11B 5/3932; G11B 5/3948; G11B 5/3951;  
G11B 5/3954  
See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

5,434,826 A 7/1995 Ravipati et al.

5,576,914 A 11/1996 Rottmayer et al.  
6,016,290 A 1/2000 Chen et al.  
6,018,441 A 1/2000 Wu et al.  
6,025,978 A 2/2000 Hoshi et al.  
6,025,988 A 2/2000 Yan  
6,032,353 A 3/2000 Hiner et al.  
6,033,532 A 3/2000 Minami  
6,034,851 A 3/2000 Zarouri et al.  
6,043,959 A 3/2000 Crue et al.  
6,046,885 A 4/2000 Aimonetti et al.  
6,049,650 A 4/2000 Jerman et al.  
6,055,138 A 4/2000 Shi  
6,058,094 A 5/2000 Davis et al.

(Continued)

**OTHER PUBLICATIONS**

Zhitao Diao, et al., U.S. Appl. No. 14/508,697, filed Oct. 7, 2014,  
29 pages.

(Continued)

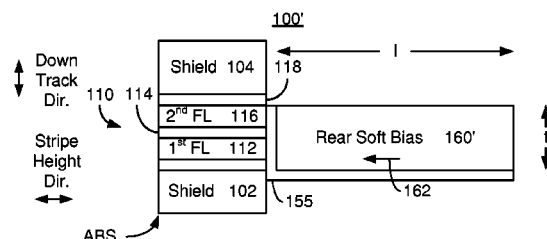
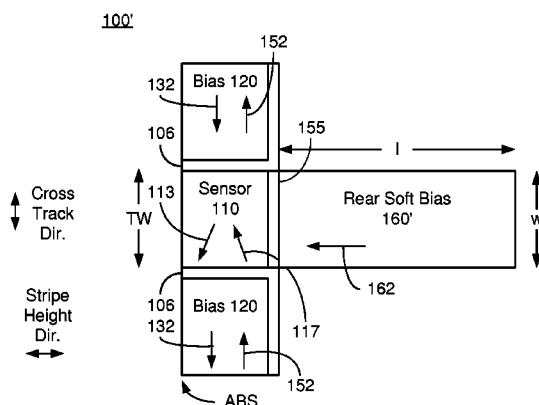
*Primary Examiner* — Will J Klimowicz

(74) *Attorney, Agent, or Firm* — Convergent Law Group  
LLP

(57) **ABSTRACT**

A magnetic read apparatus has an air-bearing surface (ABS) and includes a read sensor and a rear magnetic bias structure. The read sensor includes first and second free layers, a spacer layer and a rear surface opposite to the ABS. The spacer layer is nonmagnetic and between the first and second free layers. The read sensor has a track width in a cross track direction parallel to the ABS. The rear magnetic bias structure magnetically biases the read sensor a stripe height direction perpendicular to the ABS. The read sensor is between the ABS and the rear magnetic bias structure. The rear magnetic bias structure has a width in the cross track direction and a length in the stripe height direction. The length is greater than the width. The width of the rear magnetic bias structure is substantially equal to the track width of the read sensor.

**19 Claims, 8 Drawing Sheets**



(56)

## References Cited

## U.S. PATENT DOCUMENTS

6,073,338 A	6/2000	Liu et al.	6,376,964 B1	4/2002	Young et al.
6,078,479 A	6/2000	Nepela et al.	6,377,535 B1	4/2002	Chen et al.
6,081,499 A	6/2000	Berger et al.	6,381,095 B1	4/2002	Sin et al.
6,094,803 A	8/2000	Carlson et al.	6,381,105 B1	4/2002	Huai et al.
6,099,362 A	8/2000	Viches et al.	6,389,499 B1	5/2002	Frank, Jr. et al.
6,103,073 A	8/2000	Thayamballi	6,392,850 B1	5/2002	Tong et al.
6,108,166 A	8/2000	Lederman	6,396,660 B1	5/2002	Jensen et al.
6,118,629 A	9/2000	Huai et al.	6,399,179 B1	6/2002	Hanrahan et al.
6,118,638 A	9/2000	Knapp et al.	6,400,526 B2	6/2002	Crue, Jr. et al.
6,125,018 A	9/2000	Takagishi et al.	6,404,600 B1	6/2002	Hawwa et al.
6,130,779 A	10/2000	Carlson et al.	6,404,601 B1	6/2002	Rottmayer et al.
6,134,089 A	10/2000	Barr et al.	6,404,706 B1	6/2002	Stovall et al.
6,136,166 A	10/2000	Shen et al.	6,410,170 B1	6/2002	Chen et al.
6,137,661 A	10/2000	Shi et al.	6,411,522 B1	6/2002	Frank, Jr. et al.
6,137,662 A	10/2000	Huai et al.	6,417,998 B1	7/2002	Crue, Jr. et al.
6,160,684 A	12/2000	Heist et al.	6,417,999 B1	7/2002	Knapp et al.
6,163,426 A	12/2000	Nepela et al.	6,418,000 B1	7/2002	Gibbons et al.
6,166,891 A	12/2000	Lederman et al.	6,418,048 B1	7/2002	Sin et al.
6,173,486 B1	1/2001	Hsiao et al.	6,421,211 B1	7/2002	Hawwa et al.
6,175,476 B1	1/2001	Huai et al.	6,421,212 B1	7/2002	Gibbons et al.
6,178,066 B1	1/2001	Barr	6,424,505 B1	7/2002	Lam et al.
6,178,070 B1	1/2001	Hong et al.	6,424,507 B1	7/2002	Lederman et al.
6,178,150 B1	1/2001	Davis	6,430,009 B1	8/2002	Komaki et al.
6,181,485 B1	1/2001	He	6,430,806 B1	8/2002	Chen et al.
6,181,525 B1	1/2001	Carlson	6,433,965 B1	8/2002	Gopinathan et al.
6,185,051 B1	2/2001	Chen et al.	6,433,968 B1	8/2002	Shi et al.
6,185,077 B1	2/2001	Tong et al.	6,433,970 B1	8/2002	Knapp et al.
6,185,081 B1	2/2001	Simion et al.	6,437,945 B1	8/2002	Hawwa et al.
6,188,549 B1	2/2001	Wiitala	6,445,536 B1	9/2002	Rudy et al.
6,190,764 B1	2/2001	Shi et al.	6,445,542 B1	9/2002	Levi et al.
6,193,584 B1	2/2001	Rudy et al.	6,445,553 B2	9/2002	Barr et al.
6,195,229 B1	2/2001	Shen et al.	6,445,554 B1	9/2002	Dong et al.
6,198,608 B1	3/2001	Hong et al.	6,447,935 B1	9/2002	Zhang et al.
6,198,609 B1	3/2001	Barr et al.	6,448,765 B1	9/2002	Chen et al.
6,201,673 B1	3/2001	Rottmayer et al.	6,451,514 B1	9/2002	Iitsuka
6,204,998 B1	3/2001	Katz	6,452,742 B1	9/2002	Crue et al.
6,204,999 B1	3/2001	Crue et al.	6,452,765 B1	9/2002	Mahvan et al.
6,212,153 B1	4/2001	Chen et al.	6,456,465 B1	9/2002	Louis et al.
6,215,625 B1	4/2001	Carlson	6,459,552 B1	10/2002	Liu et al.
6,219,205 B1	4/2001	Yuan et al.	6,462,920 B1	10/2002	Karimi
6,221,218 B1	4/2001	Shi et al.	6,466,401 B1	10/2002	Hong et al.
6,222,707 B1	4/2001	Huai et al.	6,466,402 B1	10/2002	Crue, Jr. et al.
6,229,782 B1	5/2001	Wang et al.	6,466,404 B1	10/2002	Crue, Jr. et al.
6,230,959 B1	5/2001	Heist et al.	6,466,418 B1	10/2002	Hong et al.
6,233,116 B1	5/2001	Chen et al.	6,468,436 B1	10/2002	Shi et al.
6,233,125 B1	5/2001	Knapp et al.	6,469,877 B1	10/2002	Knapp et al.
6,237,215 B1	5/2001	Hunsaker et al.	6,477,019 B2	11/2002	Matono et al.
6,252,743 B1	6/2001	Bozorgi	6,479,096 B1	11/2002	Shi et al.
6,255,721 B1	7/2001	Roberts	6,483,662 B1	11/2002	Thomas et al.
6,258,468 B1	7/2001	Mahvan et al.	6,487,040 B1	11/2002	Hsiao et al.
6,266,216 B1	7/2001	Hikami et al.	6,487,056 B1	11/2002	Gibbons et al.
6,271,604 B1	8/2001	Frank, Jr. et al.	6,490,125 B1	12/2002	Barr
6,275,354 B1	8/2001	Huai et al.	6,496,330 B1	12/2002	Crue, Jr. et al.
6,277,505 B1	8/2001	Shi et al.	6,496,334 B1	12/2002	Pang et al.
6,282,056 B1	8/2001	Feng et al.	6,504,676 B1	1/2003	Hiner et al.
6,296,955 B1	10/2001	Hossain et al.	6,512,657 B2	1/2003	Heist et al.
6,297,955 B1	10/2001	Frank, Jr. et al.	6,512,659 B1	1/2003	Hawwa et al.
6,304,414 B1	10/2001	Crue, Jr. et al.	6,512,661 B1	1/2003	Louis
6,307,715 B1	10/2001	Berding et al.	6,512,690 B1	1/2003	Qi et al.
6,310,746 B1	10/2001	Hawwa et al.	6,515,573 B1	2/2003	Dong et al.
6,310,750 B1	10/2001	Hawwa et al.	6,515,791 B1	2/2003	Hawwa et al.
6,317,290 B1	11/2001	Wang et al.	6,532,823 B1	3/2003	Knapp et al.
6,317,297 B1	11/2001	Tong et al.	6,535,363 B1	3/2003	Hosomi et al.
6,322,911 B1	11/2001	Fukagawa et al.	6,552,874 B1	4/2003	Chen et al.
6,330,136 B1	12/2001	Wang et al.	6,552,928 B1	4/2003	Qi et al.
6,330,137 B1	12/2001	Knapp et al.	6,577,470 B1	6/2003	Rumpler
6,333,830 B2	12/2001	Rose et al.	6,583,961 B2	6/2003	Levi et al.
6,340,533 B1	1/2002	Ueno et al.	6,583,968 B1	6/2003	Scura et al.
6,349,014 B1	2/2002	Crue, Jr. et al.	6,597,548 B1	7/2003	Yamanaka et al.
6,351,355 B1	2/2002	Min et al.	6,611,398 B1	8/2003	Rumpler et al.
6,353,318 B1	3/2002	Sin et al.	6,618,223 B1	9/2003	Chen et al.
6,353,511 B1	3/2002	Shi et al.	6,629,357 B1	10/2003	Akoh
6,356,412 B1	3/2002	Levi et al.	6,633,464 B2	10/2003	Lai et al.
6,359,779 B1	3/2002	Frank, Jr. et al.	6,636,394 B1	10/2003	Fukagawa et al.
6,369,983 B1	4/2002	Hong	6,639,291 B1	10/2003	Sin et al.
			6,650,503 B1	11/2003	Chen et al.
			6,650,506 B1	11/2003	Risse
			6,654,195 B1	11/2003	Frank, Jr. et al.
			6,657,816 B1	12/2003	Barr et al.

(56)

## References Cited

## U.S. PATENT DOCUMENTS

6,661,621 B1	12/2003	Iitsuka	6,944,939 B2	9/2005	Guo et al.
6,661,625 B1	12/2003	Sin et al.	6,947,258 B1	9/2005	Li
6,674,610 B1	1/2004	Thomas et al.	6,950,266 B1	9/2005	McCaslin et al.
6,680,863 B1	1/2004	Shi et al.	6,954,332 B1	10/2005	Hong et al.
6,683,763 B1	1/2004	Hiner et al.	6,958,885 B1	10/2005	Chen et al.
6,687,098 B1	2/2004	Huai	6,961,221 B1	11/2005	Niu et al.
6,687,178 B1	2/2004	Qi et al.	6,969,989 B1	11/2005	Mei
6,687,977 B2	2/2004	Knapp et al.	6,975,486 B2	12/2005	Chen et al.
6,691,226 B1	2/2004	Frank, Jr. et al.	6,987,643 B1	1/2006	Seagle
6,697,294 B1	2/2004	Qi et al.	6,989,962 B1	1/2006	Dong et al.
6,700,738 B1	3/2004	Sin et al.	6,989,972 B1	1/2006	Stoev et al.
6,700,759 B1	3/2004	Knapp et al.	7,006,327 B2	2/2006	Krounbi et al.
6,704,158 B2	3/2004	Hawwa et al.	7,007,372 B1	3/2006	Chen et al.
6,707,083 B1	3/2004	Hiner et al.	7,012,832 B1	3/2006	Sin et al.
6,713,801 B1	3/2004	Sin et al.	7,016,166 B1	3/2006	Hou et al.
6,721,138 B1	4/2004	Chen et al.	7,023,658 B1	4/2006	Knapp et al.
6,721,149 B1	4/2004	Shi et al.	7,026,063 B2	4/2006	Ueno et al.
6,721,203 B1	4/2004	Qi et al.	7,027,268 B1	4/2006	Zhu et al.
6,724,569 B1	4/2004	Chen et al.	7,027,274 B1	4/2006	Sin et al.
6,724,572 B1	4/2004	Stoev et al.	7,035,046 B1	4/2006	Young et al.
6,729,015 B2	5/2004	Matono et al.	7,041,985 B1	5/2006	Wang et al.
6,735,850 B1	5/2004	Gibbons et al.	7,046,490 B1	5/2006	Ueno et al.
6,737,281 B1	5/2004	Dang et al.	7,054,113 B1	5/2006	Seagle et al.
6,744,608 B1	6/2004	Sin et al.	7,057,857 B1	6/2006	Niu et al.
6,747,301 B1	6/2004	Hiner et al.	7,059,868 B1	6/2006	Yan
6,751,055 B1	6/2004	Alfoqaha et al.	7,079,361 B2	7/2006	Sugita et al.
6,754,049 B1	6/2004	Seagle et al.	7,092,195 B1	8/2006	Liu et al.
6,756,071 B1	6/2004	Shi et al.	7,110,289 B1	9/2006	Sin et al.
6,757,140 B1	6/2004	Hawwa	7,111,382 B1	9/2006	Knapp et al.
6,760,196 B1	7/2004	Niu et al.	7,113,366 B1	9/2006	Wang et al.
6,762,910 B1	7/2004	Knapp et al.	7,114,241 B2	10/2006	Kubota et al.
6,765,756 B1	7/2004	Hong et al.	7,116,517 B1	10/2006	He et al.
6,775,902 B1	8/2004	Huai et al.	7,124,654 B1	10/2006	Davies et al.
6,778,358 B1	8/2004	Jiang et al.	7,126,788 B1	10/2006	Liu et al.
6,781,927 B1	8/2004	Heanuc et al.	7,126,790 B1	10/2006	Liu et al.
6,785,955 B1	9/2004	Chen et al.	7,126,795 B2	10/2006	Funayama et al.
6,791,793 B1	9/2004	Chen et al.	7,126,797 B2	10/2006	Hasegawa et al.
6,791,807 B1	9/2004	Hikami et al.	7,130,165 B2	10/2006	Macken et al.
6,798,616 B1	9/2004	Seagle et al.	7,131,346 B1	11/2006	Buttar et al.
6,798,625 B1	9/2004	Ueno et al.	7,133,253 B1	11/2006	Seagle et al.
6,801,408 B1	10/2004	Chen et al.	7,134,185 B1	11/2006	Knapp et al.
6,801,411 B1	10/2004	Lederman et al.	7,154,715 B2	12/2006	Yamanaka et al.
6,803,615 B1	10/2004	Sin et al.	7,155,810 B2	1/2007	Pinarbasi
6,806,035 B1	10/2004	Atireklapvarodom et al.	7,170,725 B1	1/2007	Zhou et al.
6,807,030 B1	10/2004	Hawwa et al.	7,177,117 B1	2/2007	Jiang et al.
6,807,332 B1	10/2004	Hawwa	7,193,815 B1	3/2007	Stoev et al.
6,809,899 B1	10/2004	Chen et al.	7,196,880 B1	3/2007	Anderson et al.
6,816,345 B1	11/2004	Knapp et al.	7,199,974 B1	4/2007	Alfoqaha
6,828,897 B1	12/2004	Nepela	7,199,975 B1	4/2007	Pan
6,829,160 B1	12/2004	Qi et al.	7,211,339 B1	5/2007	Seagle et al.
6,829,819 B1	12/2004	Crue, Jr. et al.	7,212,384 B1	5/2007	Stoev et al.
6,833,979 B1	12/2004	Knapp et al.	7,229,706 B2	6/2007	Hasegawa et al.
6,834,010 B1	12/2004	Qi et al.	7,238,292 B1	7/2007	He et al.
6,859,343 B1	2/2005	Alfoqaha et al.	7,239,478 B1	7/2007	Sin et al.
6,859,997 B1	3/2005	Tong et al.	7,248,431 B1	7/2007	Liu et al.
6,861,937 B1	3/2005	Feng et al.	7,248,433 B1	7/2007	Stoev et al.
6,870,712 B2	3/2005	Chen et al.	7,248,449 B1	7/2007	Seagle
6,873,494 B2	3/2005	Chen et al.	7,268,985 B2	9/2007	Freitag et al.
6,873,547 B1	3/2005	Shi et al.	7,275,304 B2	10/2007	Sakai et al.
6,879,464 B2	4/2005	Sun et al.	7,280,325 B1	10/2007	Pan
6,888,184 B1	5/2005	Shi et al.	7,283,327 B1	10/2007	Liu et al.
6,888,704 B1	5/2005	Diao et al.	7,284,316 B1	10/2007	Huai et al.
6,891,702 B1	5/2005	Tang	7,286,329 B1	10/2007	Chen et al.
6,894,871 B2	5/2005	Alfoqaha et al.	7,289,303 B1	10/2007	Sin et al.
6,894,877 B1	5/2005	Crue, Jr. et al.	7,292,409 B1	11/2007	Stoev et al.
6,906,894 B2	6/2005	Chen et al.	7,296,339 B1	11/2007	Yang et al.
6,909,578 B1	6/2005	Missell et al.	7,301,734 B2	11/2007	Guo et al.
6,912,106 B1	6/2005	Chen et al.	7,307,814 B1	12/2007	Seagle et al.
6,914,759 B2	7/2005	Chen et al.	7,307,818 B1	12/2007	Park et al.
6,934,113 B1	8/2005	Chen	7,310,204 B1	12/2007	Stoev et al.
6,934,129 B1	8/2005	Zhang et al.	7,318,947 B1	1/2008	Park et al.
6,940,688 B2	9/2005	Jiang et al.	7,333,295 B1	2/2008	Medina et al.
6,942,824 B1	9/2005	Li	7,337,530 B1	3/2008	Stoev et al.
6,943,993 B2	9/2005	Chang et al.	7,342,752 B1	3/2008	Zhang et al.
6,944,938 B1	9/2005	Crue, Jr. et al.	7,349,170 B1	3/2008	Rudman et al.
			7,349,179 B1	3/2008	He et al.
			7,354,664 B1	4/2008	Jiang et al.
			7,363,697 B1	4/2008	Dunn et al.
			7,371,152 B1	5/2008	Newman

(56)

## References Cited

## U.S. PATENT DOCUMENTS

7,372,665	B1	5/2008	Stoev et al.	8,011,084	B2	9/2011	Le et al.
7,375,926	B1	5/2008	Stoev et al.	8,012,804	B1	9/2011	Wang et al.
7,379,269	B1	5/2008	Krounbi et al.	8,014,108	B2	9/2011	Shimazawa et al.
7,386,933	B1	6/2008	Krounbi et al.	8,015,692	B1	9/2011	Zhang et al.
7,389,577	B1	6/2008	Shang et al.	8,015,694	B2	9/2011	Carey et al.
7,417,832	B1	8/2008	Erickson et al.	8,018,677	B1	9/2011	Chung et al.
7,419,891	B1	9/2008	Chen et al.	8,018,678	B1	9/2011	Zhang et al.
7,428,124	B1	9/2008	Song et al.	8,018,691	B2	9/2011	Gill et al.
7,430,098	B1	9/2008	Song et al.	8,023,230	B2	9/2011	Machita et al.
7,436,620	B1	10/2008	Kang et al.	8,024,748	B1	9/2011	Moravec et al.
7,436,638	B1	10/2008	Pan	8,031,445	B2	10/2011	Zhou et al.
7,440,220	B1	10/2008	Kang et al.	8,049,997	B2	11/2011	Miyauchi et al.
7,443,632	B1	10/2008	Stoev et al.	8,072,705	B1	12/2011	Wang et al.
7,444,740	B1	11/2008	Chung et al.	8,074,345	B1	12/2011	Anguelouch et al.
7,446,987	B2	11/2008	Zhang et al.	8,077,418	B1	12/2011	Hu et al.
7,468,870	B2	12/2008	Arasawa et al.	8,077,434	B1	12/2011	Shen et al.
7,493,688	B1	2/2009	Wang et al.	8,077,435	B1	12/2011	Liu et al.
7,508,627	B1	3/2009	Zhang et al.	8,077,557	B1	12/2011	Hu et al.
7,515,388	B2	4/2009	Zhang et al.	8,079,135	B1	12/2011	Shen et al.
7,522,377	B1	4/2009	Jiang et al.	8,081,403	B1	12/2011	Chen et al.
7,522,379	B1	4/2009	Krounbi et al.	8,091,210	B1	1/2012	Sasaki et al.
7,522,382	B1	4/2009	Pan	8,094,420	B2	1/2012	Ayukawa et al.
7,542,246	B1	6/2009	Song et al.	8,097,846	B1	1/2012	Anguelouch et al.
7,551,406	B1	6/2009	Thomas et al.	8,104,166	B1	1/2012	Zhang et al.
7,552,523	B1	6/2009	He et al.	8,116,043	B2	2/2012	Leng et al.
7,554,767	B1	6/2009	Hu et al.	8,116,171	B1	2/2012	Lee
7,580,230	B2	8/2009	Freitag et al.	8,125,856	B1	2/2012	Li et al.
7,583,466	B2	9/2009	Kermiche et al.	8,130,475	B2	3/2012	Kawamori et al.
7,595,967	B1	9/2009	Moon et al.	8,134,794	B1	3/2012	Wang
7,599,158	B2	10/2009	Wang et al.	8,136,224	B1	3/2012	Sun et al.
7,615,996	B1	11/2009	Machita et al.	8,136,225	B1	3/2012	Zhang et al.
7,639,457	B1	12/2009	Chen et al.	8,136,805	B1	3/2012	Lee
7,660,080	B1	2/2010	Liu et al.	8,141,235	B1	3/2012	Zhang
7,672,080	B1	3/2010	Tang et al.	8,144,437	B2	3/2012	Miyauchi et al.
7,672,086	B1	3/2010	Jiang	8,146,236	B1	4/2012	Luo et al.
7,675,718	B2	3/2010	Chang et al.	8,147,994	B2	4/2012	Matsuzawa et al.
7,684,160	B1	3/2010	Erickson et al.	8,149,536	B1	4/2012	Yang et al.
7,688,546	B1	3/2010	Bai et al.	8,151,441	B1	4/2012	Rudy et al.
7,691,434	B1	4/2010	Zhang et al.	8,163,185	B1	4/2012	Sun et al.
7,695,761	B1	4/2010	Shen et al.	8,164,760	B2	4/2012	Willis
7,719,795	B2	5/2010	Hu et al.	8,164,855	B1	4/2012	Gibbons et al.
7,726,009	B1	6/2010	Liu et al.	8,164,864	B2	4/2012	Kaiser et al.
7,729,086	B1	6/2010	Song et al.	8,165,709	B1	4/2012	Rudy
7,729,087	B1	6/2010	Stoev et al.	8,166,631	B1	5/2012	Tran et al.
7,736,823	B1	6/2010	Wang et al.	8,166,632	B1	5/2012	Zhang et al.
7,785,666	B1	8/2010	Sun et al.	8,169,473	B1	5/2012	Yu et al.
7,796,356	B1	9/2010	Fowler et al.	8,171,618	B1	5/2012	Wang et al.
7,800,858	B1	9/2010	Bajikar et al.	8,179,636	B1	5/2012	Bai et al.
7,804,668	B2	9/2010	Zhou et al.	8,179,642	B2	5/2012	Kawamori et al.
7,819,979	B1	10/2010	Chen et al.	8,191,237	B1	6/2012	Luo et al.
7,826,179	B2	11/2010	Shimazawa et al.	8,194,363	B2	6/2012	Hara et al.
7,829,264	B1	11/2010	Wang et al.	8,194,365	B1	6/2012	Leng et al.
7,839,606	B2	11/2010	Jayasekara	8,194,366	B1	6/2012	Li et al.
7,843,668	B2	11/2010	Machita et al.	8,196,285	B1	6/2012	Zhang et al.
7,846,643	B1	12/2010	Sun et al.	8,200,054	B1	6/2012	Li et al.
7,848,065	B2	12/2010	Freitag et al.	8,203,800	B2	6/2012	Li et al.
7,855,854	B2	12/2010	Hu et al.	8,208,350	B1	6/2012	Hu et al.
7,855,859	B2	12/2010	Hara et al.	8,220,140	B1	7/2012	Wang et al.
7,869,160	B1	1/2011	Pan et al.	8,222,599	B1	7/2012	Chien
7,872,824	B1	1/2011	Macchioni et al.	8,225,488	B1	7/2012	Zhang et al.
7,872,833	B2	1/2011	Hu et al.	8,225,489	B2	7/2012	Miyauchi et al.
7,881,023	B2	2/2011	Machita et al.	8,227,023	B1	7/2012	Liu et al.
7,894,166	B2	2/2011	Yamazaki et al.	8,228,633	B1	7/2012	Tran et al.
7,894,167	B2	2/2011	Kanaya et al.	8,231,796	B1	7/2012	Li et al.
7,898,776	B2	3/2011	Nakabayashi et al.	8,233,247	B2	7/2012	Carey et al.
7,910,267	B1	3/2011	Zeng et al.	8,233,248	B1	7/2012	Li et al.
7,911,735	B1	3/2011	Sin et al.	8,248,896	B1	8/2012	Yuan et al.
7,911,737	B1	3/2011	Jiang et al.	8,254,060	B1	8/2012	Shi et al.
7,916,426	B2	3/2011	Hu et al.	8,257,597	B1	9/2012	Guan et al.
7,918,013	B1	4/2011	Dunn et al.	8,259,410	B1	9/2012	Bai et al.
7,961,438	B2	6/2011	Mizuno et al.	8,259,539	B1	9/2012	Hu et al.
7,968,219	B1	6/2011	Jiang et al.	8,262,918	B1	9/2012	Li et al.
7,974,048	B2	7/2011	Shimazawa et al.	8,262,919	B1	9/2012	Luo et al.
7,982,989	B1	7/2011	Shi et al.	8,264,797	B2	9/2012	Emley
8,008,912	B1	8/2011	Shang	8,264,798	B1	9/2012	Guan et al.
				8,270,126	B1	9/2012	Roy et al.
				8,274,764	B2	9/2012	Hara et al.
				8,276,258	B1	10/2012	Tran et al.
				8,277,669	B1	10/2012	Chen et al.

(56)

## References Cited

## U.S. PATENT DOCUMENTS

8,279,719 B1	10/2012	Hu et al.	8,493,693 B1	7/2013	Zheng et al.
8,284,517 B1	10/2012	Sun et al.	8,493,695 B1	7/2013	Kaiser et al.
8,288,204 B1	10/2012	Wang et al.	8,495,813 B1	7/2013	Hu et al.
8,289,821 B1	10/2012	Huber	8,498,084 B1	7/2013	Leng et al.
8,291,743 B1	10/2012	Shi et al.	8,506,828 B1	8/2013	Osugi et al.
8,307,539 B1	11/2012	Rudy et al.	8,514,517 B1	8/2013	Batra et al.
8,307,540 B1	11/2012	Tran et al.	8,518,279 B1	8/2013	Wang et al.
8,308,921 B1	11/2012	Hiner et al.	8,518,832 B1	8/2013	Yang et al.
8,310,785 B1	11/2012	Zhang et al.	8,520,336 B1	8/2013	Liu et al.
8,310,901 B1	11/2012	Batra et al.	8,520,337 B1	8/2013	Liu et al.
8,315,019 B1	11/2012	Mao et al.	8,524,068 B2	9/2013	Medina et al.
8,316,527 B2	11/2012	Hong et al.	8,526,275 B1	9/2013	Yuan et al.
8,320,076 B1	11/2012	Shen et al.	8,531,801 B1	9/2013	Xiao et al.
8,320,077 B1	11/2012	Tang et al.	8,532,450 B1	9/2013	Wang et al.
8,320,219 B1	11/2012	Wolf et al.	8,533,937 B1	9/2013	Wang et al.
8,320,220 B1	11/2012	Yuan et al.	8,537,494 B1	9/2013	Pan et al.
8,320,722 B1	11/2012	Yuan et al.	8,537,495 B1	9/2013	Luo et al.
8,322,022 B1	12/2012	Yi et al.	8,537,502 B1	9/2013	Park et al.
8,322,023 B1	12/2012	Zeng et al.	8,545,999 B1	10/2013	Leng et al.
8,325,569 B1	12/2012	Shi et al.	8,547,659 B1	10/2013	Bai et al.
8,333,008 B1	12/2012	Sin et al.	8,547,667 B1	10/2013	Roy et al.
8,334,093 B2	12/2012	Zhang et al.	8,547,730 B1	10/2013	Shen et al.
8,336,194 B2	12/2012	Yuan et al.	8,553,369 B2	10/2013	Song et al.
8,339,738 B1	12/2012	Tran et al.	8,555,486 B1	10/2013	Medina et al.
8,341,826 B1	1/2013	Jiang et al.	8,559,141 B1	10/2013	Pakala et al.
8,343,319 B1	1/2013	Li et al.	8,563,146 B1	10/2013	Zhang et al.
8,343,364 B1	1/2013	Gao et al.	8,565,049 B1	10/2013	Tanner et al.
8,349,195 B1	1/2013	Si et al.	8,576,517 B1	11/2013	Tran et al.
8,351,307 B1	1/2013	Wolf et al.	8,578,594 B2	11/2013	Jiang et al.
8,357,244 B1	1/2013	Zhao et al.	8,582,238 B1	11/2013	Liu et al.
8,369,048 B2	2/2013	Miyauchi et al.	8,582,241 B1	11/2013	Yu et al.
8,373,945 B1	2/2013	Luo et al.	8,582,247 B2	11/2013	Song et al.
8,375,564 B1	2/2013	Luo et al.	8,582,253 B1	11/2013	Zheng et al.
8,375,565 B2	2/2013	Hu et al.	8,588,039 B1	11/2013	Shi et al.
8,381,391 B2	2/2013	Park et al.	8,593,914 B2	11/2013	Wang et al.
8,385,157 B1	2/2013	Champion et al.	8,597,528 B1	12/2013	Roy et al.
8,385,158 B1	2/2013	Hu et al.	8,599,520 B1	12/2013	Liu et al.
8,394,280 B1	3/2013	Wan et al.	8,599,657 B1	12/2013	Lee
8,400,731 B1	3/2013	Li et al.	8,603,593 B1	12/2013	Roy et al.
8,404,128 B1	3/2013	Zhang et al.	8,607,438 B1	12/2013	Gao et al.
8,404,129 B1	3/2013	Luo et al.	8,607,439 B1	12/2013	Wang et al.
8,405,930 B1	3/2013	Li et al.	8,609,262 B2	12/2013	Horng et al.
8,409,453 B1	4/2013	Jiang et al.	8,611,035 B1	12/2013	Bajikar et al.
8,413,317 B1	4/2013	Wan et al.	8,611,054 B1	12/2013	Shang et al.
8,416,540 B1	4/2013	Li et al.	8,611,055 B1	12/2013	Pakala et al.
8,419,953 B1	4/2013	Su et al.	8,614,864 B1	12/2013	Hong et al.
8,419,954 B1	4/2013	Chen et al.	8,619,512 B1	12/2013	Yuan et al.
8,422,176 B1	4/2013	Leng et al.	8,625,233 B1	1/2014	Ji et al.
8,422,342 B1	4/2013	Lee	8,625,941 B1	1/2014	Shi et al.
8,422,841 B1	4/2013	Shi et al.	8,628,672 B1	1/2014	Si et al.
8,424,192 B1	4/2013	Yang et al.	8,630,068 B1	1/2014	Mauri et al.
8,441,756 B1	5/2013	Sun et al.	8,634,280 B1	1/2014	Wang et al.
8,443,510 B1	5/2013	Shi et al.	8,638,529 B1	1/2014	Leng et al.
8,444,866 B1	5/2013	Guan et al.	8,643,980 B1	2/2014	Fowler et al.
8,449,948 B2	5/2013	Medina et al.	8,649,123 B1	2/2014	Zhang et al.
8,451,556 B1	5/2013	Wang et al.	8,665,561 B1	3/2014	Knutson et al.
8,451,563 B1	5/2013	Zhang et al.	8,670,211 B1	3/2014	Sun et al.
8,454,846 B1	6/2013	Zhou et al.	8,670,213 B1	3/2014	Zeng et al.
8,455,119 B1	6/2013	Jiang et al.	8,670,214 B1	3/2014	Knutson et al.
8,456,961 B1	6/2013	Wang et al.	8,670,217 B1	3/2014	Braganca et al.
8,456,963 B1	6/2013	Hu et al.	8,670,294 B1	3/2014	Shi et al.
8,456,964 B1	6/2013	Yuan et al.	8,670,295 B1	3/2014	Hu et al.
8,456,966 B1	6/2013	Shi et al.	8,675,318 B1	3/2014	Ho et al.
8,456,967 B1	6/2013	Mallary	8,675,455 B1	3/2014	Krichevsky et al.
8,458,892 B2	6/2013	Si et al.	8,681,594 B1	3/2014	Shi et al.
8,462,592 B1	6/2013	Wolf et al.	8,689,430 B1	4/2014	Chen et al.
8,468,682 B1	6/2013	Zhang	8,693,141 B1	4/2014	Elliot et al.
8,472,288 B1	6/2013	Wolf et al.	8,703,397 B1	4/2014	Zeng et al.
8,477,461 B2	7/2013	Chou et al.	8,705,205 B1	4/2014	Li et al.
8,480,911 B1	7/2013	Osugi et al.	8,705,212 B2	4/2014	Gadbois et al.
8,486,285 B2	7/2013	Zhou et al.	8,711,518 B1	4/2014	Zeng et al.
8,486,286 B1	7/2013	Gao et al.	8,711,528 B1	4/2014	Xiao et al.
8,488,272 B1	7/2013	Tran et al.	8,717,709 B1	5/2014	Shi et al.
8,491,801 B1	7/2013	Tanner et al.	8,720,044 B1	5/2014	Tran et al.
8,491,802 B1	7/2013	Gao et al.	8,721,902 B1	5/2014	Wang et al.
			8,724,259 B1	5/2014	Liu et al.
			8,749,790 B1	6/2014	Tanner et al.
			8,749,920 B1	6/2014	Knutson et al.
			8,749,926 B1	6/2014	Le et al.

(56)

## References Cited

## U.S. PATENT DOCUMENTS

- |              |      |         |                    |                          |
|--------------|------|---------|--------------------|--------------------------|
| 8,753,903    | B1   | 6/2014  | Tanner et al.      |                          |
| 8,760,807    | B1   | 6/2014  | Zhang et al.       |                          |
| 8,760,818    | B1   | 6/2014  | Diao et al.        |                          |
| 8,760,819    | B1   | 6/2014  | Liu et al.         |                          |
| 8,760,822    | B1   | 6/2014  | Li et al.          |                          |
| 8,760,823    | B1   | 6/2014  | Chen et al.        |                          |
| 8,763,235    | B1   | 7/2014  | Wang et al.        |                          |
| 8,780,498    | B1   | 7/2014  | Jiang et al.       |                          |
| 8,780,505    | B1   | 7/2014  | Xiao               |                          |
| 8,786,983    | B1   | 7/2014  | Liu et al.         |                          |
| 8,790,524    | B1   | 7/2014  | Luo et al.         |                          |
| 8,790,527    | B1   | 7/2014  | Luo et al.         |                          |
| 8,792,208    | B1   | 7/2014  | Liu et al.         |                          |
| 8,792,312    | B1   | 7/2014  | Wang et al.        |                          |
| 8,793,866    | B1   | 8/2014  | Zhang et al.       |                          |
| 8,797,680    | B1   | 8/2014  | Luo et al.         |                          |
| 8,797,684    | B1   | 8/2014  | Tran et al.        |                          |
| 8,797,686    | B1   | 8/2014  | Bai et al.         |                          |
| 8,797,692    | B1   | 8/2014  | Guo et al.         |                          |
| 8,813,324    | B2   | 8/2014  | Emley et al.       |                          |
| 8,842,396    | B1   | 9/2014  | Zhu                |                          |
| 8,891,208    | B2   | 11/2014 | Degawa et al.      |                          |
| 8,913,349    | B2   | 12/2014 | Yamane et al.      |                          |
| 9,007,725    | B1 * | 4/2015  | Diao               | G11B 5/3909<br>360/236.5 |
| 9,076,468    | B1 * | 7/2015  | Keener             | G11B 5/3932              |
| 9,099,122    | B2 * | 8/2015  | Jiang              | G11B 5/3903              |
| 9,147,404    | B1 * | 9/2015  | Luo                | G11B 5/33                |
| 9,153,258    | B2 * | 10/2015 | Le                 | G11B 5/3906              |
| 2002/0024777 | A1   | 2/2002  | Funayama et al.    |                          |
| 2002/0039264 | A1   | 4/2002  | Ohsawa et al.      |                          |
| 2005/0275975 | A1   | 12/2005 | Zhang et al.       |                          |
| 2006/0109592 | A1   | 5/2006  | Watanabe et al.    |                          |
| 2007/0217077 | A1   | 9/2007  | Kanaya et al.      |                          |
| 2007/0285849 | A1   | 12/2007 | Jayasekara         |                          |
| 2009/0073616 | A1   | 3/2009  | Shimazawa et al.   |                          |
| 2009/0135529 | A1   | 5/2009  | Shimazawa et al.   |                          |
| 2009/0168264 | A1   | 7/2009  | Hara et al.        |                          |
| 2009/0180217 | A1   | 7/2009  | Chou et al.        |                          |
| 2009/0190272 | A1   | 7/2009  | Machita et al.     |                          |
| 2009/0201612 | A1   | 8/2009  | Shimazawa et al.   |                          |
| 2009/0207534 | A1   | 8/2009  | Miyauchi et al.    |                          |
| 2009/0213502 | A1   | 8/2009  | Miyauchi et al.    |                          |
| 2009/0273864 | A1   | 11/2009 | Machita et al.     |                          |
| 2009/0290264 | A1   | 11/2009 | Ayukawa et al.     |                          |
| 2009/0303779 | A1   | 12/2009 | Chen et al.        |                          |
| 2010/0027168 | A1   | 2/2010  | Chou et al.        |                          |
| 2010/0053820 | A1   | 3/2010  | Miyauchi et al.    |                          |
| 2010/0079917 | A1   | 4/2010  | Miyauchi et al.    |                          |
| 2010/0103562 | A1   | 4/2010  | Machita et al.     |                          |
| 2010/0103563 | A1   | 4/2010  | Machita et al.     |                          |
| 2010/0149689 | A1   | 6/2010  | Tsuchiya et al.    |                          |
| 2010/0214696 | A1   | 8/2010  | Matsuzawa et al.   |                          |
| 2010/0214700 | A1   | 8/2010  | Hara et al.        |                          |
| 2010/0232066 | A1   | 9/2010  | Hara et al.        |                          |
| 2010/0232073 | A1   | 9/2010  | Chou et al.        |                          |
| 2010/0290157 | A1   | 11/2010 | Zhang et al.       |                          |
| 2011/0026169 | A1   | 2/2011  | Gill et al.        |                          |
| 2011/0051291 | A1   | 3/2011  | Miyauchi et al.    |                          |
| 2011/0069417 | A1   | 3/2011  | Kawamori et al.    |                          |
| 2011/0086240 | A1   | 4/2011  | Xiang et al.       |                          |
| 2011/0091744 | A1   | 4/2011  | Kawamori et al.    |                          |
| 2011/0215800 | A1   | 9/2011  | Zhou et al.        |                          |
| 2011/0232079 | A1   | 9/2011  | Miyauchi et al.    |                          |
| 2011/0235216 | A1   | 9/2011  | Lin                |                          |
| 2011/0273802 | A1   | 11/2011 | Zhou et al.        |                          |
| 2011/0317313 | A1   | 12/2011 | Miyauchi et al.    |                          |
| 2012/0111826 | A1   | 5/2012  | Chen et al.        |                          |
| 2012/0129007 | A1   | 5/2012  | Zheng et al.       |                          |
| 2012/0216378 | A1   | 8/2012  | Emley et al.       |                          |
| 2012/0237878 | A1   | 9/2012  | Zeng et al.        |                          |
| 2012/0275062 | A1   | 11/2012 | Gao                |                          |
| 2012/0281319 | A1   | 11/2012 | Singleton et al.   |                          |
| 2012/0281320 | A1   | 11/2012 | Singleton et al.   |                          |
| 2012/0298621 | A1   | 11/2012 | Gao                |                          |
| 2013/0069642 | A1   | 3/2013  | Sapozhnikov et al. |                          |
| 2013/0149559 | A1   | 6/2013  | Covington et al.   |                          |
| 2013/0216702 | A1   | 8/2013  | Kaiser et al.      |                          |
| 2013/0216863 | A1   | 8/2013  | Li et al.          |                          |
| 2013/0257421 | A1   | 10/2013 | Shang et al.       |                          |
| 2014/0002930 | A1   | 1/2014  | Dimitrov et al.    |                          |
| 2014/0035075 | A1   | 2/2014  | Zhu et al.         |                          |
| 2014/0154529 | A1   | 6/2014  | Yang et al.        |                          |
| 2014/0175050 | A1   | 6/2014  | Zhang et al.       |                          |
| 2014/0268405 | A1   | 9/2014  | Machita et al.     |                          |
| 2015/0002961 | A1 * | 1/2015  | Keener             | G11B 5/3163<br>360/235.4 |
| 2015/0154990 | A1   | 6/2015  | Jiang et al.       |                          |
| 2015/0154991 | A1   | 6/2015  | Le et al.          |                          |

## OTHER PUBLICATIONS

Anup G. Roy, et al., U.S. Appl. No. 14/310,122, filed Jun. 20, 2014, 34 pages.

Office Action dated Sep. 30, 2014 from U.S. Appl. No. 14/310,122, 18 pages.

"Scissors-type trilayer giant magnetoresistive sensor using heusler alloy ferromagnet," <http://phys.org/news/2011-11-scissors-type-trilayer-giant-magnetoresistive-sensor.html>, downloaded on Jul. 29, 2014, pp. 1-9.

Han, et al., "Perspectives of Read Head Technology for 10 Tb/in<sup>2</sup> Recording", IEEE Transactions on Magnetism, Volume:46, No. 3, Mar. 2010, pp. 709-714.

Jiang-Gang (Jimmy) Zhu, "New heights for hard disk drives," MaterialsToday, Jul./Aug. 2003, pp. 22-30.

Wang, et al., "Downtrack response of differential reader for high density magnetic recording," Data Storage Institute, Agency for Science, Technology and Research (A\*STAR), pp. 1-13.

Robert Lamberton, et al., "Current-in-Plane GMR Trilayer Head Design for Hard-Disk Drives: Characterization and Extendibility," IEEE Transactions on Magnetism, vol. 43, No. 2, Feb. 2007, pp. 645-650.

Feng Liu, et al., U.S. Appl. No. 14/670,340, filed Mar. 26, 2015, 31 pages.

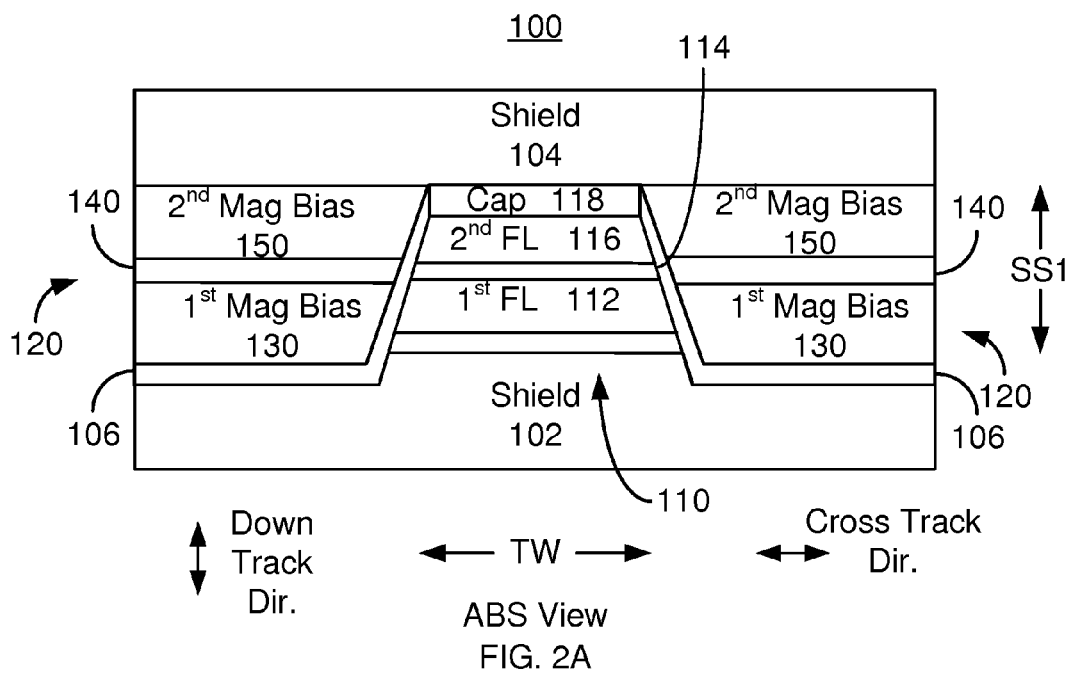
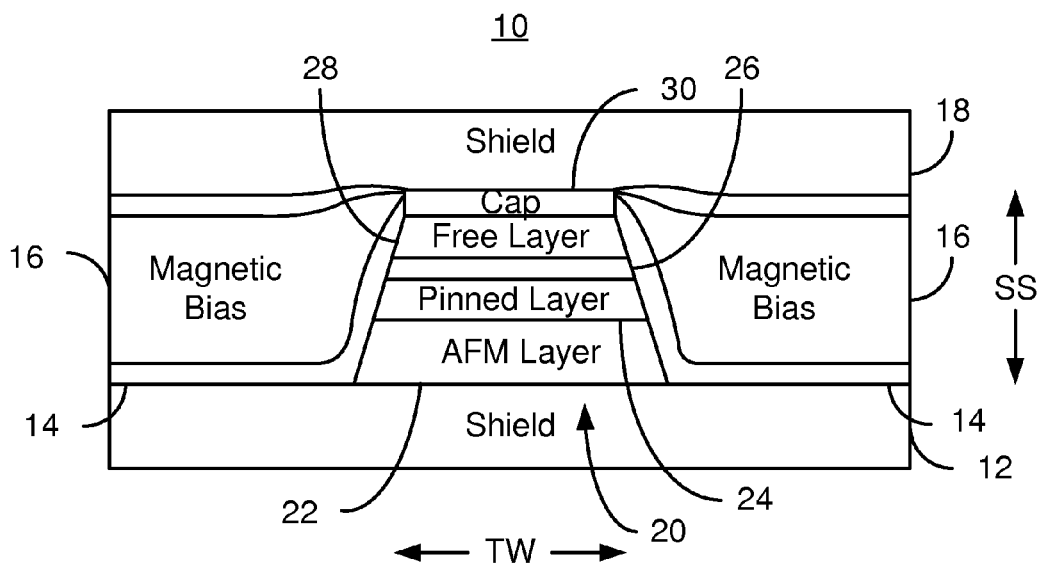
Anup G. Roy, et al., U.S. Appl. No. 14/621,712, filed Feb. 13, 2015, 30 pages.

"Scissors-type Trilayer Giant Magnetoresistive Sensor using Heusler Alloy Ferromagnet for Narrow Reader of Ultra-high Density Hard Disk Drives," <http://www.nims.go.jp/eng/news/press/2011/10/p201110310.html>, downloaded on Jul. 29, 2014, pp. 1-3.

Ex parte Quayle Action dated Dec. 30, 2015 from U.S. Appl. No. 14/670,340, 9 pages.

Notice of Allowance dated Mar. 15, 2016 from U.S. Appl. No. 14/670,340, 5 pages.

\* cited by examiner



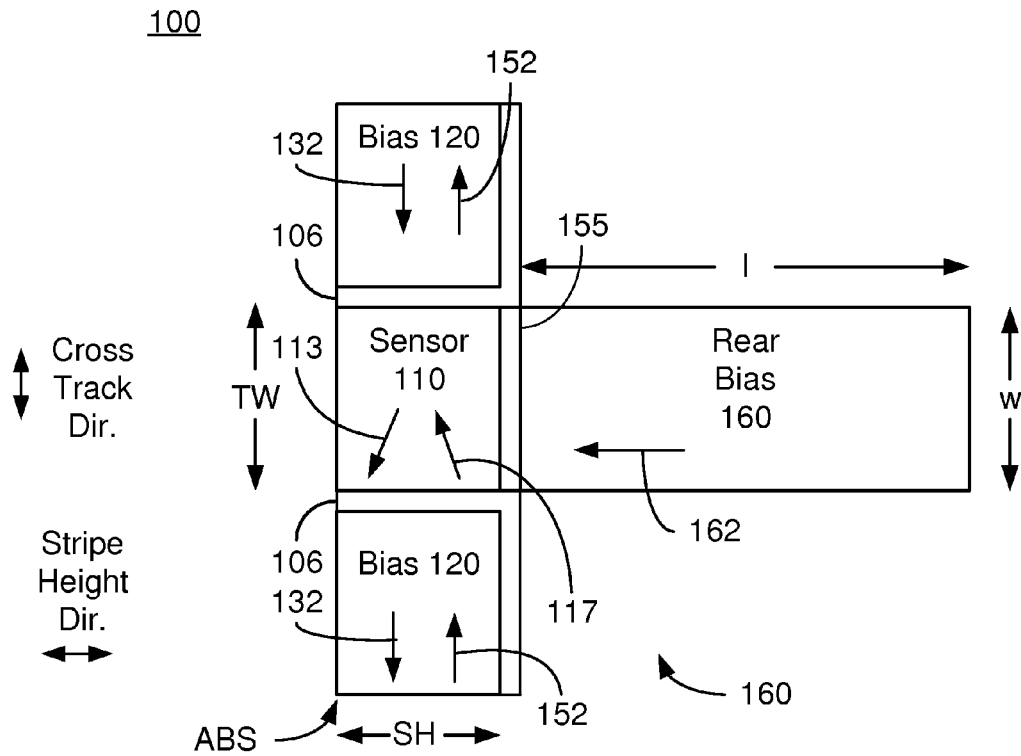


FIG. 2B

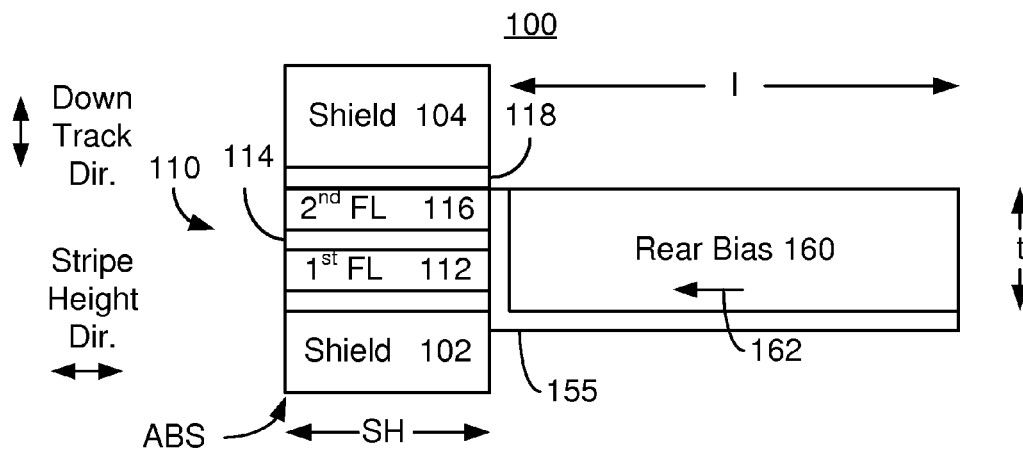


FIG. 2C



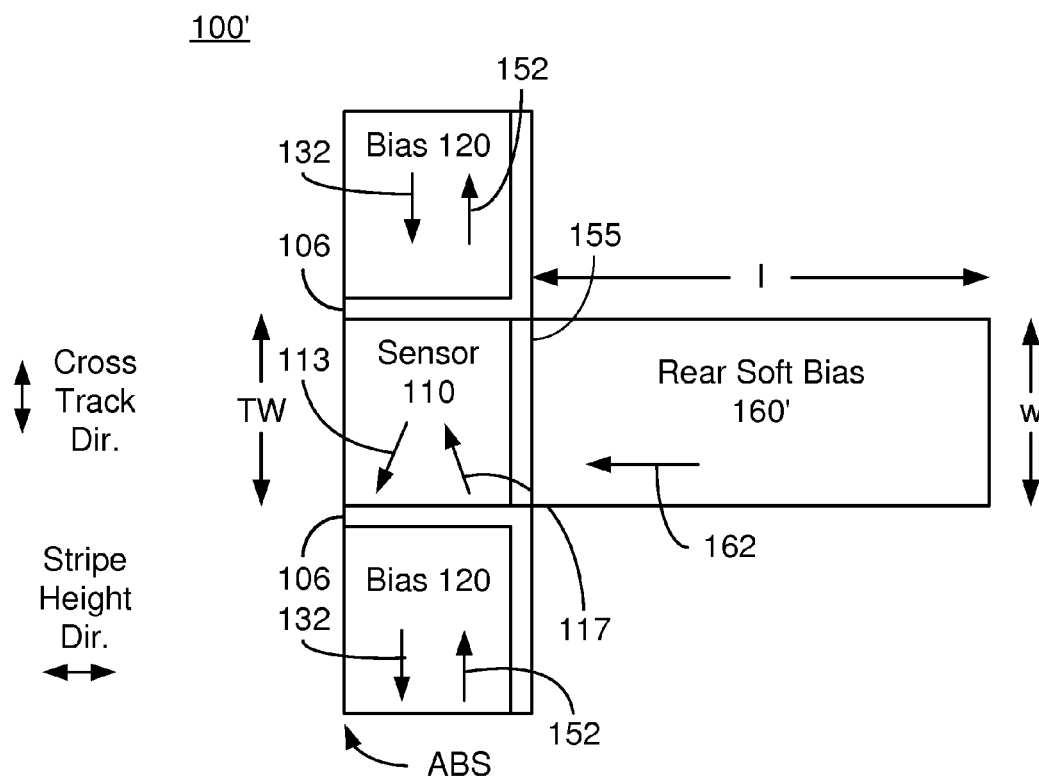


FIG. 3A

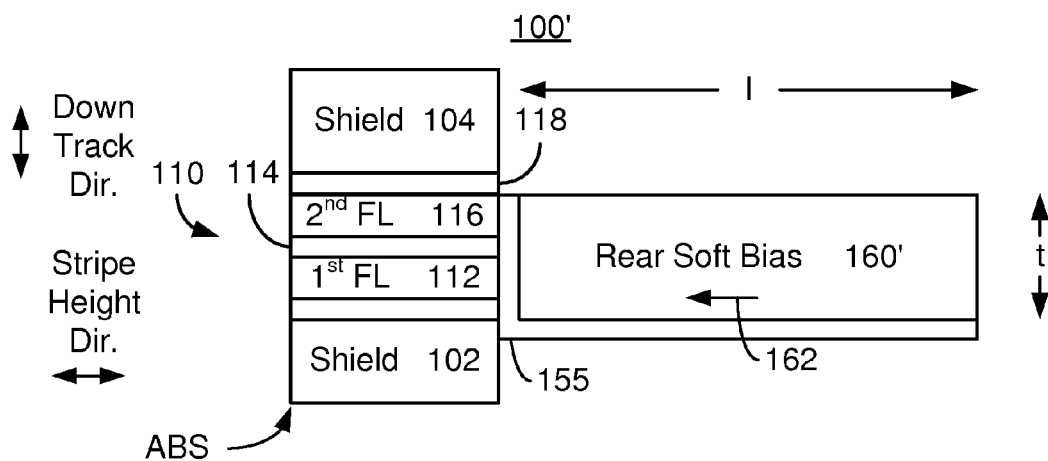
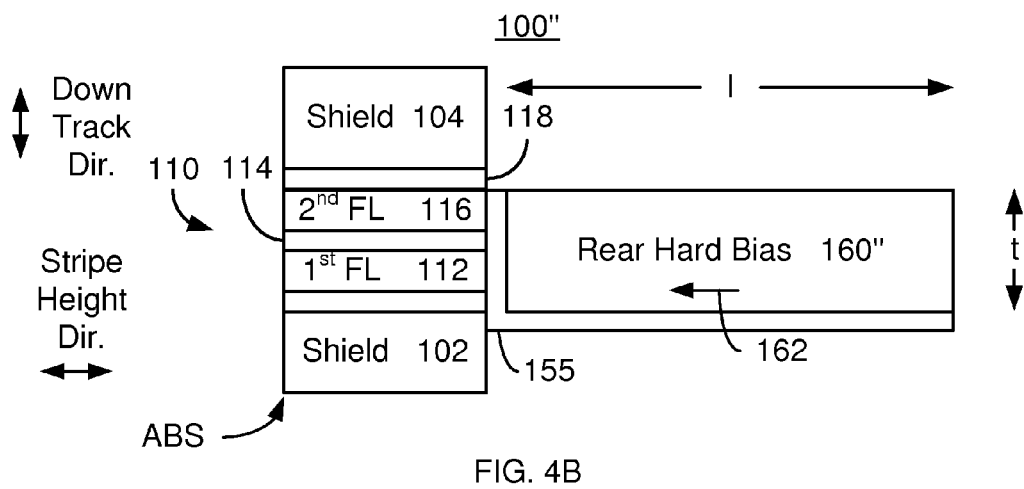
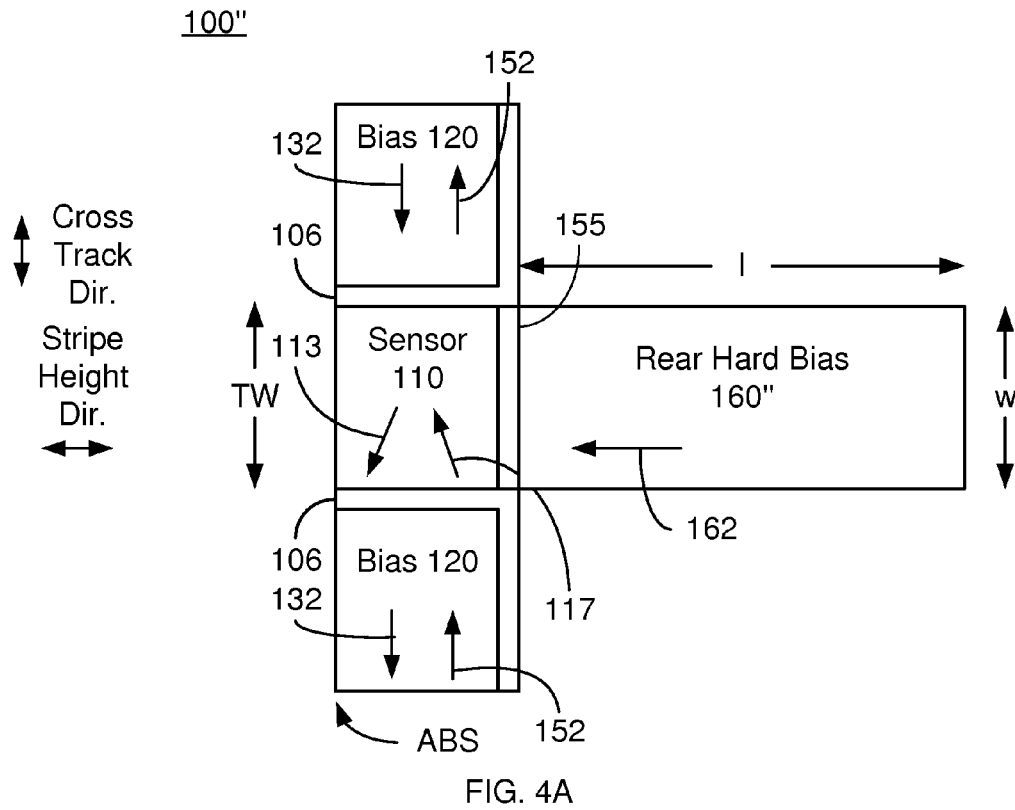


FIG. 3B



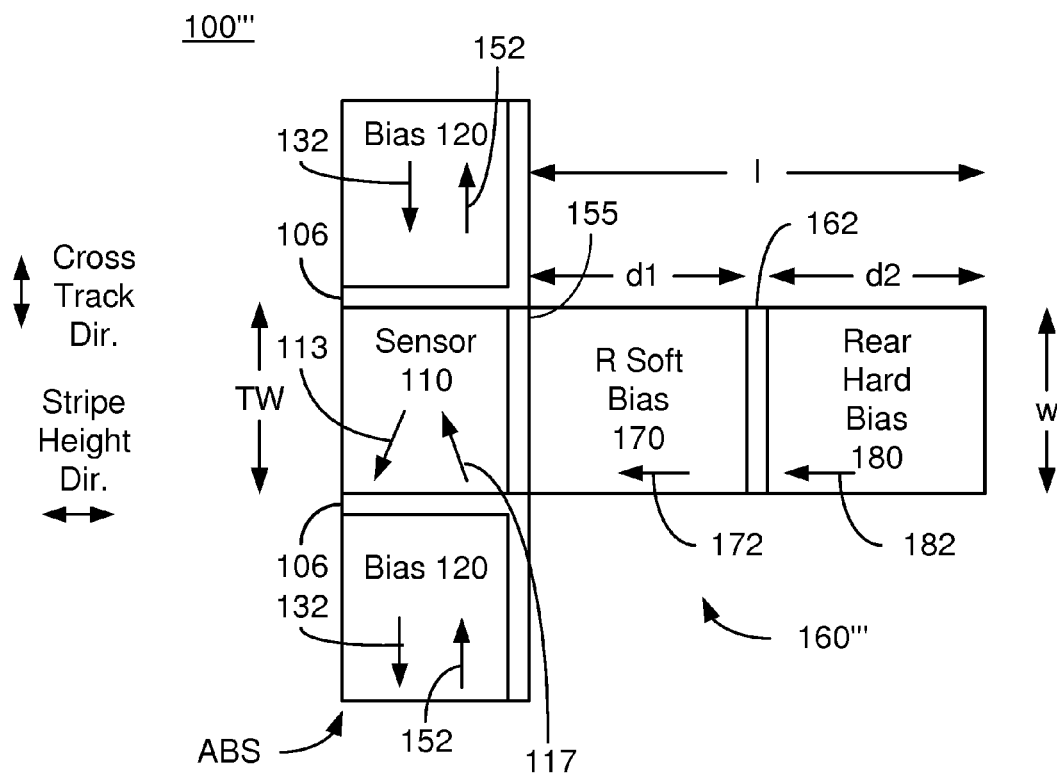


FIG. 5A

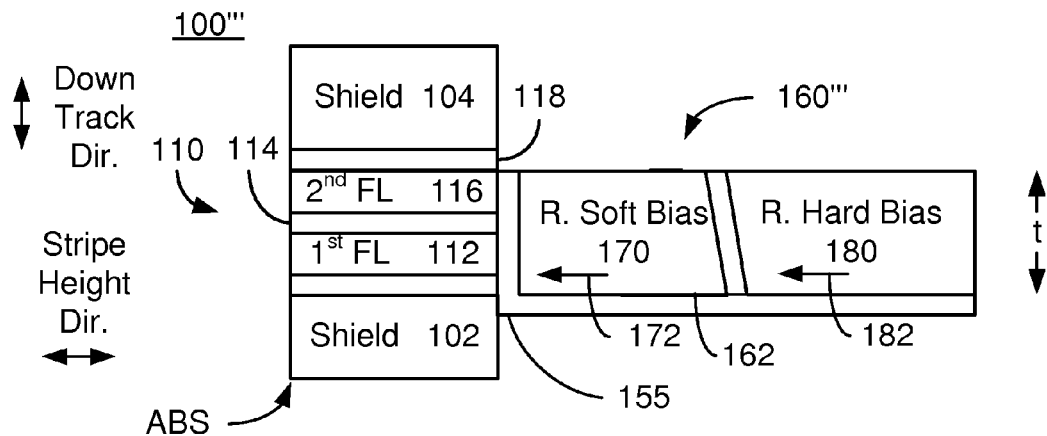


FIG. 5B

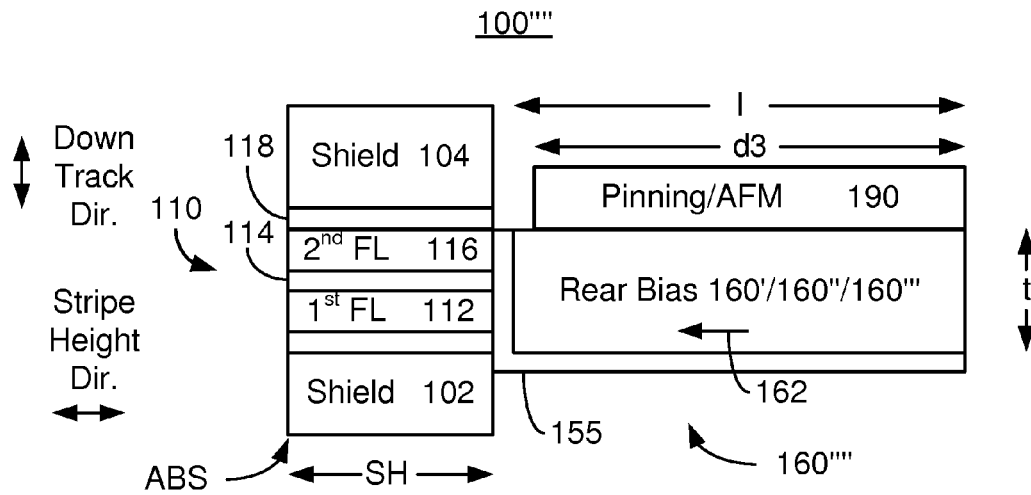


FIG. 6

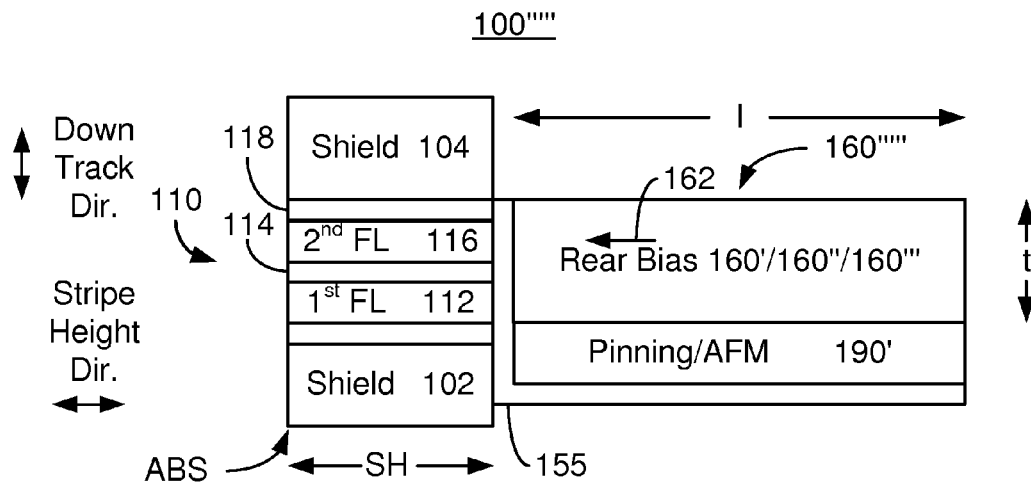


FIG. 7

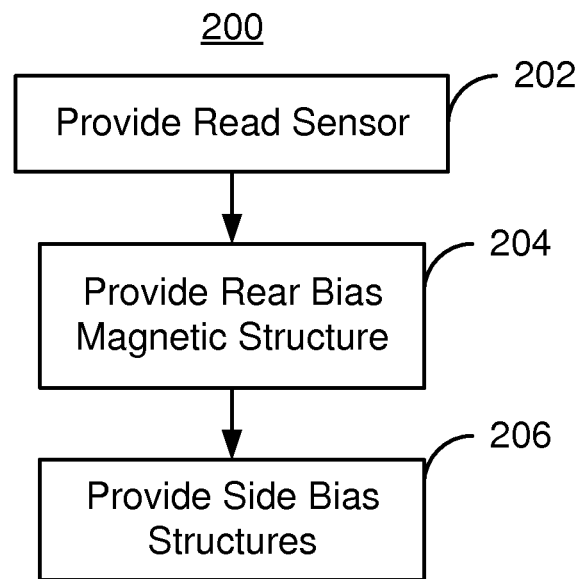


FIG. 8

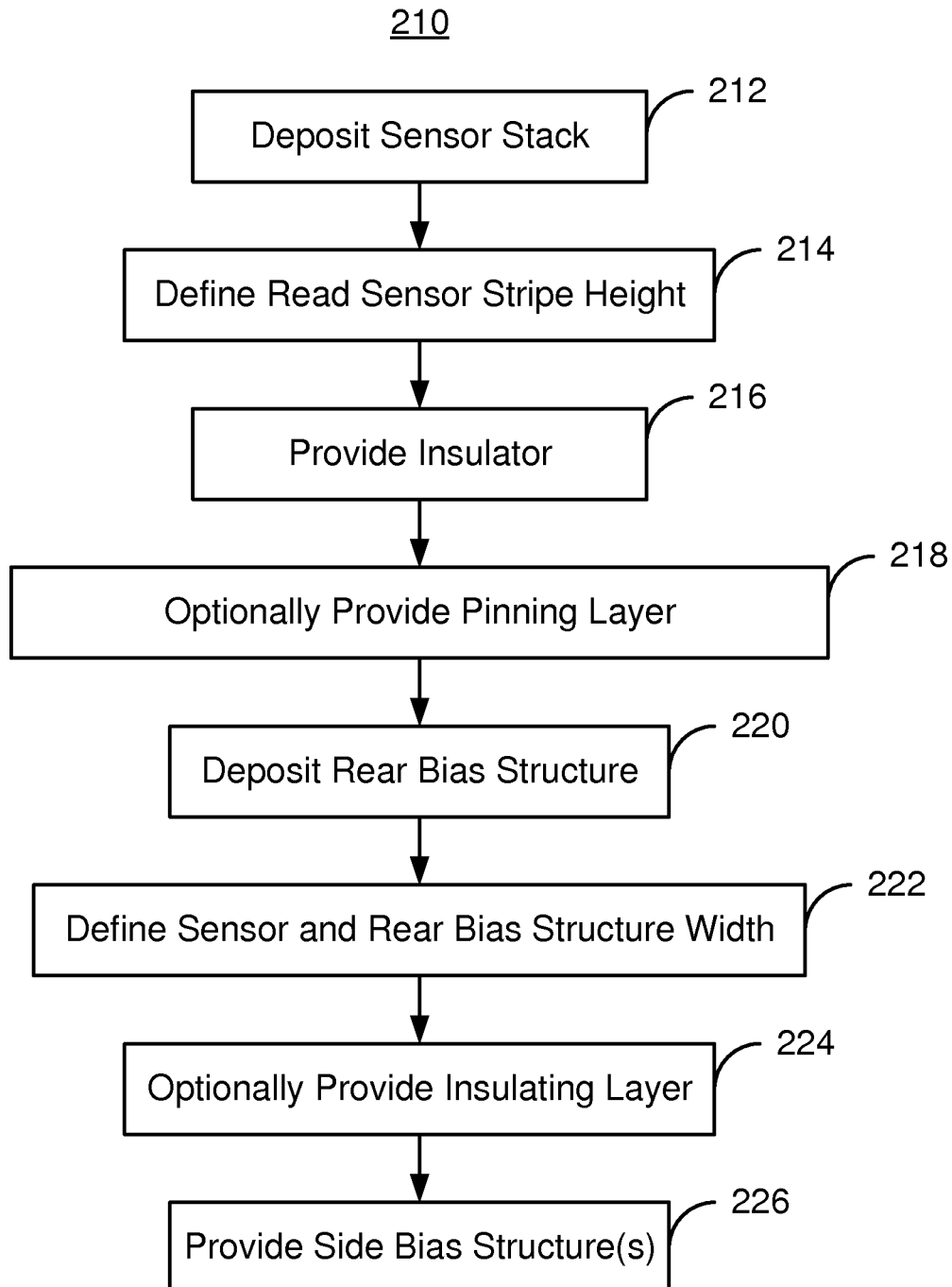


FIG. 9

1

# DUAL FREE LAYER MAGNETIC READER HAVING A REAR BIAS STRUCTURE HAVING A HIGH ASPECT RATIO

## CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of co-pending U.S. patent application Ser. No. 14/670,340, filed on Mar. 26, 2015, (F7730), and incorporated herein by reference.

## BACKGROUND

FIG. 1 depicts an air-bearing surface (ABS) view of a conventional read transducer used in magnetic recording technology applications. The conventional read transducer 10 includes shields 12 and 18, insulator 14, magnetic bias structures 16, and sensor 20. The read sensor 20 is typically a giant magnetoresistive (GMR) sensor or tunneling magnetoresistive (TMR) sensor. The read sensor 20 includes an antiferromagnetic (AFM) layer 22, a pinned layer 24, a nonmagnetic spacer layer 26, and a free layer 28. Also shown is a capping layer 30. In addition, seed layer(s) may be used. The free layer 28 has a magnetization sensitive to an external magnetic field. Thus, the free layer 28 functions as a sensor layer for the magnetoresistive sensor 20. If the sensor 20 is to be used in a current perpendicular to plane (CPP) configuration, then current is driven in a direction substantially perpendicular to the plane of the layers 22, 24, 26, and 28. Conversely, in a current-in-plane (CIP) configuration, then conductive leads (not shown) would be provided on the magnetic bias structures 16. The magnetic bias structures 16 are used to magnetically bias the free layer 28.

Although the conventional transducer 10 functions, there are drawbacks. The trend in magnetic recording is to higher density memories. The conventional read sensor 20 may not adequately read high density media. As a result, dual free layer magnetic read sensors have been developed. In such read sensors, two free layers that are biased in a scissor state by a hard magnet. The read sensor may not, however, be reliable in such a conventional magnetic reader. Such reliability issues may become particularly acute at high densities and lower track widths on the order of less than or equal to thirty nanometers. For example, in such high density dual free layer readers, the state in which the free layers are biased may be unpredictable. Accordingly, what is needed is a system and method for improving the performance of a magnetic recording read transducer.

## BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 depicts an ABS view of a conventional magnetic recording read transducer.

FIGS. 2A-2C depicts ABS, plan and side views of an exemplary embodiment of a portion of a dual free layer magnetic read transducer.

FIGS. 3A-3B depict plan and side views of another exemplary embodiment of a portion of a dual free layer magnetic read transducer.

FIGS. 4A-4B depict plan and side views of another exemplary embodiment of a portion of a dual free layer magnetic read transducer.

FIGS. 5A-5B depict plan and side views of another exemplary embodiment of a portion of a dual free layer magnetic read transducer.

2

FIG. 6 depicts a side view of another exemplary embodiment of a portion of a dual free layer magnetic read transducer.

FIG. 7 depicts a side view of another exemplary embodiment of a portion of a dual free layer magnetic read transducer.

FIG. 8 is flow chart depicting an exemplary embodiment of a method for providing a magnetic recording read transducer.

FIG. 9 is flow chart depicting another exemplary embodiment of a method for providing a magnetic recording read transducer.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 2A-2C depict ABS, plan and side views of an exemplary embodiment of a portion of a magnetic read transducer 100. For clarity, FIGS. 2A-2C are not to scale. The read transducer 100 may be part of a read head or may be part of a merged head that also includes a write transducer. The head of which the read transducer 100 is a part is contained in a disk drive having a media, a slider and the head coupled with the slider. Further, only a portion of the components of the read transducer 100 are depicted.

The transducer 100 includes optional soft magnetic shields 102 and 104, insulator 106, read sensor 110, side bias structures 130 and 150 and rear bias structure 160 that may be separated from the read sensor 110 by an insulating layer 155. The read sensor 110 includes a first free layer 112 and a second free layer 116 separated by a nonmagnetic spacer layer 114. The nonmagnetic spacer layer 114 may be conductive or an insulating tunneling barrier layer, such as MgO. The read sensor 110 is, therefore, a giant magnetoresistive or tunneling magnetoresistive read sensor in the embodiment shown. The free layers 112 and 116 are ferromagnetic and may include multiple layers. The free layers 112 and 116 are biased such that their magnetic moments 113 and 117, respectively are in a scissor mode. Based on the angle between the magnetic moments 113 and 117, the resistance of the read sensor 110 changes. This angle changes when the read 110 is under the influence of an external field, for example due to a bit being read. Thus, the resistance of the read sensor 110 may be used to read data. The read sensor 110 may also be configured for high density recording. Thus, in some embodiments, the track width (TW) of the read sensor 110 is not more than thirty nanometers. In some such embodiments, the track width is not more than twenty nanometers. In the embodiment shown, the shields 102 and 104 and the free layers 112 and 116 all have a stripe height, SH, in the stripe height direction. In other embodiments, however, different structures 102, 104, 112 and 116 may have different stripe heights.

The transducer 100 includes side magnetic bias structures 120 and a rear magnetic bias structure 160 that together magnetically bias the free layers 112 and 116 in a scissor mode. As can be seen in FIGS. 2A and 2B, the side bias structures 120 bias the magnetic moments 113 and 117, respectively, of the free layers 112 and 116, respectively, parallel to the ABS, in the cross-track direction. The magnetic bias structures 120 and free layers 112 and 116 are also configured to bias the magnetic moments 113 and 117 of the free layers 112 and 116, respectively, antiparallel. In some embodiments, the magnetic moments 113 and 117 of the free layers 112 and 116 are antiferromagnetically coupled. The rear magnetic bias structure 160 biases the magnetic

3

moments **113** and **117** of the free layers **112** and **116**, respectively, perpendicular to the ABS, in the stripe height direction.

Each bias structure **120** includes two magnetic bias structures **130** and **150** separated by a nonmagnetic structure **140**. The first magnetic bias structure **130** magnetically biases the free layer **112** and, therefore, is adjacent to the sides of the free layer in the cross-track direction. Similarly, the second magnetic bias structure **150** magnetically biases the free layer **116** and is thus adjacent to the side of the free layer **116** in the cross-track direction. In the embodiment shown, the top surface of the first magnetic bias structure **130** is not higher than the upper surface of the first free layer **112**. However, in other embodiments, the top surface of the magnetic bias structure **130** may be at another location. In some embodiments, the top surface of the first magnetic bias structure **130** is not higher than the lower surface of the second free layer **116**. In other embodiments, the top surface of the first magnetic bias structure **130** is not higher than midway between the upper and lower surfaces of the second free layer **116**. Although the top of the first magnetic bias structure **130** may be higher than bottom of the second free layer **116**, the entire magnetic bias structure **130** is still lower than the second magnetic bias structure **150**. Similarly, the bottom surface of the second magnetic bias structure **150** is not lower than the lower surface of the second free layer **116** in the embodiment depicted in FIGS. 2A-2C. However, in other embodiments, the bottom surface of the magnetic bias structure **150** may be at another location. For example, the bottom surface of the second magnetic bias structure **150** may not be lower than the upper surface of the first free layer **112**. In other embodiments, the bottom surface of the magnetic structure **150** is not lower than midway between the upper and lower surfaces of the first free layer **112**. Although the bottom of the second magnetic bias structure **150** may be lower than upper surface of the first free layer **112**, the entire magnetic bias structure **150** is still higher than the first magnetic bias structure **130**.

The magnetic bias structures **130** and **150** may take various forms. In some embodiments, both the first magnetic bias structure **130** and the second magnetic bias structure **150** are soft magnetic structures. For example, the magnetic bias structures **130** and **150** may be an alloy, multilayer or other structure that has a coercivity of not more than ten Oe. In some such embodiments, the soft magnetic bias structure(s) **130** and/or **150** have a coercivity of not more than five Oe. For example, the magnetic bias structures **130** and **150** may include CoFe and/or NiFe. In other embodiments, the magnetic bias structures **130** and/or **150** may have different magnetic properties. In some embodiments, the magnetic bias structure **130** and/or **150** may be a hard bias structure. For example, the first magnetic bias structure **130** may be an alloy or multilayer that has a sufficiently high coercivity to have its magnetic moment **132** substantially unchanged during operation of the transducer **100**. In other embodiments, the first magnetic bias structure **130** may be a pinned structure. In such an embodiment, the first magnetic bias structure **130** may include a pinning layer, such as an antiferromagnetic (AFM) layer and a soft magnetic layer adjoining the pinning layer. In still other embodiments, the magnetic bias structure **130** and **150** may be configured in another manner. For example, the shield **102** is shown as being overmilled to allow for the soft bias structures **130** and **150**. However, in other embodiments, the shield **102** may not be overmilled.

The first magnetic bias structure **130** may have a magnetic moment **132**. The second magnetic bias structure **152** may

4

have a magnetic moment **152**. As can be seen in FIG. 2B, the magnetic moments **132** and **152** are antiferromagnetically aligned. Stated differently, the steady state orientation of the magnetic moments **132** and **152** is antiparallel. In some embodiments, the bias structures **130** and **150**, and thus the magnetic moments **132** and **152**, are antiferromagnetically coupled. Because of the orientations of the magnetic moments **132** and **152**, the magnetic moment **113** of the first free layer **112** is biased in one direction, while the magnetic moment **117** of the second free layer **116** is biased in the opposite direction.

The magnetic transducer **100** also includes a rear magnetic bias structure **160**. The rear bias structure may be a soft magnetic bias structure, a hard magnetic bias structure, or include both soft and hard magnetic bias structures. For example, a hard magnetic bias structure may be a magnetic structure having a coercivity of greater than one hundred Oersted. In some embodiments, the hard magnetic bias structure coercivity is at least one thousand Oersted. In contrast, a soft magnetic bias structure may have a coercivity of less than one hundred Oersted. In some embodiments, the soft magnetic bias structure coercivity is not more than ten Oersted. The hard and soft bias structure may include single alloys, multiple layer(s), a mixed-composition alloy and/or other components. Other components, such as a pinning structure, may be included in the rear bias structure **160**. A pinning structure is a magnetic component used to magnetically bias other portions of the rear magnetic bias structure **160**. For example, the pinning structure might be an antiferromagnetic (AFM) layer.

The read sensor **110** is between the rear bias structure **160** and the ABS. Further, an insulating layer **155** may separate the rear bias structure **160** from the sensor **110** and bias structures **120**. Such an insulating layer **155** may be used if the rear bias structure **160** is conductive. In addition, although the shields **102** and **104** are shown as extending only to the stripe height of the sensor **110**, the shields **102** and **104** generally extend significantly further in the stripe height direction. However, the shields **102** and **104** are also magnetically decoupled from the rear bias structure **160**. Thus, the insulating layer **155** and a top insulating (not shown) may extend along the depth of the rear bias structure **160**. For example, in some embodiments, the insulating layer **155** is at least ten Angstroms and not more than forty Angstroms thick. The insulating layer **155** is also nonmagnetic. Thus, the read sensor **110** may be electrically insulated from the rear bias structure **160** and not exchanged coupled with the rear soft bias structure **160**. Although not depicted in FIGS. 2A-2C, an insulating capping layer may also be provided on top of the rear bias structure **160**.

The rear bias structure **160** is shown having a width, *w*, in the cross-track direction; a length, *l*, in the stripe height direction and a thickness, *t*, in the down track direction. The width of the rear bias structure **160** is substantially equal to the track width, *TW*, of the read sensor **110**. In some embodiments, this is because the sensor **110** and rear bias structure **160** are defined in the cross-track direction using a single mask. Stated differently, the rear bias structure **160** and sensor **110** may be self-aligned. In addition, the length, *l*, is greater than the width (*l* ≥ *w*). Thus, the rear bias structure **160** has a shape anisotropy that is perpendicular to the ABS.

The magnetic moment **162** of the rear bias structure **160** is used to bias the sensor **110** in the stripe height direction. Consequently, the rear bias structure **160** has a magnetic anisotropy in the stripe height direction. This anisotropy may arise from one or more effects. For example, the rear bias structure **160** may have a shape anisotropy. In some



5

embodiments, the length is at least four multiplied by the width. In some such embodiments, the length is at least ten multiplied by the width. The rear bias structure **160** may have a crystalline anisotropy that favors a perpendicular-to-ABS orientation of the magnetic moment **162**. The rear bias structure **160** may have a magnetic anisotropy due to deposition in a magnetic field. In some embodiments, the rear bias structure **160** may have a magnetoelastic anisotropy, for example due to magnetostriction. In other embodiments, a pinning layer (not shown in FIGS. 2A-2C) or other structure (not shown) may be used to induce the magnetic anisotropy in the rear bias structure **160**. In some embodiments, such a magnetic anisotropy is consistent with a reversal field of at least one thousand Oersted. In some such embodiments, the reversal field is at least five thousand Oersted.

Further, the rear bias structure **160** provides sufficient moment to bias the magnetic moments **113** and **117** of the free layers **112** and **116**, respectively. For example, in some embodiments, the rear soft bias structure has a saturation magnetization-thickness product of at least one milli-emu/cm<sup>2</sup> and not more than three milli-emu/cm<sup>2</sup>. In some such embodiments, the saturation magnetization-thickness product is not more than two milli-emu per cm<sup>2</sup>. The thickness used in the saturation magnetization-thickness product is *t*, the depth of the rear bias structure **160** in the down track direction.

The magnetic transducer **100** may be suitable for use in high density magnetic recording applications, for example those having a sensor track width (and thus rear bias structure **160** width) of not more than thirty nanometers. In some embodiments, the track width and rear bias structure width may be not greater than twenty nanometers. The read sensor **110** may not include an antiferromagnetic layer or a pinned layer. Consequently, the shield-to-shield spacing (SS1) between the shields **102** and **104** may be reduced. The use of the scissor mode may also enhance the read signal. This scissor mode may be more reliably achieved because of the presence of the rear bias structure **160**. In particular, the shape anisotropy, width and other aspects of the rear bias structure **160** may allow for more reliable biasing of the read sensor. The desired scissor mode may be achieved and performance may be improved.

FIGS. 3A and 3B depict various views of another embodiment of a magnetic read transducer **100'**. FIG. 3A depicts a plan view of an exemplary embodiment of the transducer **100'**. FIG. 3B depicts a side view of the transducer **100'**. For clarity, FIGS. 3A and 3B are not to scale. The read transducer **100'** may be part of a read head or may be part of a merged head that also includes a write transducer. The head of which the read transducer **100'** is a part is part of a disk drive having a media, a slider and the head coupled with the slider. The transducer **100'** corresponds to the transducer **100**. Consequently, analogous components are labeled similarly. For example, the transducer **100'** includes a read sensor **110** having free layers **112** and **116** separated by a nonmagnetic spacer layer **114** that are analogous to such structures in the transducer **100**. Thus, the components **102**, **104**, **110**, **112**, **114** **116**, **155** and **160'** have a similar structure and function to the components **102**, **104**, **110**, **112**, **114** **116**, **155** and **160**, respectively, depicted in FIGS. 2A-2C. Further, although an ABS view is not shown, the transducer **100'** may appear substantially the same from the ABS as the transducer **100**. The transducer **100'** may also include structures analogous to the structures **120**, **130**, **140** and **150** depicted in FIGS. 2A-2C.

In the embodiment shown in FIGS. 3A-3B, the rear bias structure **160'** consists of a rear soft bias structure **160'**. Thus,

6

the coercivity of the rear bias structure **160'** is less than one hundred Oe. In some such embodiments, the coercivity of the rear soft bias structure **160'** is less than ten Oe. The rear soft bias structure **160'** may be configured such that the magnetization **162** is stable perpendicular to the ABS. For example, the rear soft bias structure **160'** may have a magnetic anisotropy such that the magnetization **162** is stable during operation of the magnetic read transducer **100'**. For example, a shape anisotropy may be used to stabilize the magnetization **162**. In some embodiments, the length, *l*, of the rear soft bias structure **160'** may be much greater than the width, *w*, or height, *t*. In the embodiment shown, the height, *t*, of the rear soft bias structure **160'** is shown as the same as that of the read sensor **110**. However, the heights may differ. However, the width of the rear soft bias structure **160'** is substantially the same as the track width of the sensor **110** (TW=*w* to within processing limitations). In some embodiments the length is at least four times the width (*l*≥4*w*). In some such embodiments, the length is at least ten multiplied by the width (*l*≥10*w*).

The magnetic transducer **100'** shares the benefits of the magnetic transducer **100**. Performance and biasing of the sensor **110** may thus be improved.

FIGS. 4A and 4B depict various views of another embodiment of a magnetic read transducer **100''**. FIG. 4A depicts a plan view of an exemplary embodiment of the transducer **100''**. FIG. 4B depicts a side view of the transducer **100''**. For clarity, FIGS. 4A and 4B are not to scale. The read transducer **100''** may be part of a read head or may be part of a merged head that also includes a write transducer. The head of which the read transducer **100''** is a part is part of a disk drive having a media, a slider and the head coupled with the slider. The transducer **100''** corresponds to the transducer **100**. Consequently, analogous components are labeled similarly. For example, the transducer **100''** includes a read sensor **110** having free layers **112** and **116** separated by a nonmagnetic spacer layer **114** that are analogous to such structures in the transducer **100**. Thus, the components **102**, **104**, **110**, **112**, **114** **116**, **155** and **160''** have a similar structure and function to the components **102**, **104**, **110**, **112**, **114** **116**, **155** and **160**, respectively, depicted in FIGS. 2A-2C. Further, although an ABS view is not shown, the transducer **100''** may appear substantially the same from the ABS as the transducer **100/100'**. The transducer **100''** may also include structures analogous to the structures **120**, **130**, **140** and **150** depicted in FIGS. 2A-2C.

In the embodiment shown in FIGS. 4A-4B, the rear bias structure **160''** consists of a rear hard bias structure **160''**. Thus, the coercivity of the rear bias structure **160''** is greater than one hundred Oe. In some such embodiments, the coercivity of the rear hard bias structure **160''** is greater than one thousand Oe. The rear hard bias structure **160''** may be configured such that the magnetization **162''** is stable perpendicular to the ABS. For example, the rear hard bias structure **160''** may have an anisotropy such that the magnetization **162''** is stable during operation of the magnetic read transducer **100''**. For example, a shape anisotropy may be used to stabilize the magnetization **162''**. In some embodiments, the length, *l*, of the rear hard bias structure **160''** may be much greater than the width, *w*, or height, *t*. In the embodiment shown, the height, *t*, of the rear hard bias structure **160''** is shown as the same as that of the read sensor **110**. However, the heights may differ. However, the width of the rear hard bias structure **160''** is substantially the same as the track width of the sensor **110** (TW=*w* to within processing limitations). In some embodiments the length is at least

four times the width ( $l \geq 4w$ ). In some such embodiments, the length is at least ten multiplied by the width ( $l \geq 10w$ ).

The magnetic transducer **100** shares the benefits of the magnetic transducer **100**. Performance and biasing of the sensor **110** may thus be improved.

FIGS. **5A** and **5B** depict another embodiment of a magnetic read transducer **100**". FIG. **5A** depicts a plan view of an exemplary embodiment of the transducer **100**". FIG. **5B** depicts a side view of the transducer **100**". For clarity, FIGS. **5A** and **5B** are not to scale. The read transducer **100**" may be part of a read head or may be part of a merged head that also includes a write transducer. The head of which the read transducer **100**" is a part is part of a disk drive having a media, a slider and the head coupled with the slider. The transducer **100**" corresponds to the transducer(s) **100**, **100'** and/or **100"**. Consequently, analogous components are labeled similarly. For example, the transducer **100**" includes a read sensor **110** having free layers **112** and **116** separated by a nonmagnetic spacer layer **114** that are analogous to such structures in the transducer(s) **100**, **100'** and/or **100"**. Thus, the components **102**, **104**, **110**, **112**, **114**, **116**, **155**, **160**" have a similar structure and function to the components **102**, **104**, **110**, **112**, **114**, **116**, **155**, **160/160'/160"**, respectively, depicted in FIGS. **2A-4B**. Further, although an ABS view is not shown, the transducer **100**" may appear substantially the same from the ABS as the transducer **100**. The transducer **100**" may also include structures analogous to the structures **120**, **130**, **140** and **150** depicted in FIGS. **2A-2C**.

The rear bias structure **160**" includes at least a rear soft bias structure **170** and a rear hard bias structure **180**. The rear soft bias structure **170** is between the rear hard bias structure **180** and the sensor **110** as well as between the rear hard bias structure **180** and the ABS. The rear hard bias structure **180** may be a hard magnetic alloy, for example having a coercivity analogous to that discussed above for structure **160**". For example, a CoPt alloy might be used. In other embodiments, the rear bias structure **180** may be a multilayer or other structure that functions as a hard bias structure.

The rear soft bias structure **170** is a soft bias structure. Thus, the coercivity of the rear soft bias structure **170** is analogous to that of the rear bias structure **160'**. Further, the rear soft bias structure **170** provides sufficient moment to bias the magnetic moments **113** and **117** of the free layers **112** and **116**, respectively. For example, in some embodiments, the rear soft bias structure has a saturation magnetization-thickness product of at least one milli-emu/cm<sup>2</sup> and not more than three milli-emu/cm<sup>2</sup>. In some such embodiments, the saturation magnetization-thickness product is not more than two milli-emu per cm<sup>2</sup>. The thickness used in the saturation magnetization-thickness product is  $t$ , the depth of the rear soft bias structure **170** in the down track direction.

The rear soft bias structure **170** has a magnetic moment **172** that biases the free layers **112** and **116** in a direction perpendicular to the bias direction from the magnetic bias structures **130** and **150**. In the embodiment shown, this direction is perpendicular to the ABS. Similarly, the rear hard bias structure **180** has a magnetic moment **182** in a direction perpendicular to the ABS. Without the rear bias structure **160**, the free layers **112** and **116** may be biased antiparallel. However, because the structures **130**, **150** and **160** all magnetically bias the free layers **112** and **116**, the free layers **112** and **116** are biased such that the magnetic moments **113** and **117** are in a scissor mode.

In some embodiments, the rear hard bias structure **180** is separated from the rear soft bias structure **170** by the nonmagnetic layer **162**. The nonmagnetic layer **162** may be conductive. In some embodiments, the thickness of the

nonmagnetic layer **162** in the stripe height direction is at least ten Angstroms and not more than forty Angstroms.

In the embodiment shown in FIGS. **5A-5B**, the rear hard bias structure **180** and rear soft bias structure **170** have similar geometries. In particular, the thicknesses are the same. However, in other embodiments, the thicknesses may differ. In the embodiment shown, the rear soft bias structure **170** has a length,  $d1$  in the stripe height direction, while the hard bias structure **180** has length  $d2$  in the stripe height direction. The total length,  $l$ , of the structure has an analogous relationship to the width,  $w$ , as described above. Further, the width of the structure **160**" is the same as the track width of the sensor ( $w = TW$  to within processing tolerances). The rear bias structures **170** and **180** have their magnetic moments **172** and **182**, respectively, perpendicular to the ABS to bias the free layers **112** and **116** into a scissor state.

The magnetic transducer **100**" shares the benefits of the magnetic transducer(s) **100** and/or **100'**. Further, omission of the nonmagnetic layer **162** between the soft bias structure **170** and the hard bias structure **180** may improve coupling between the structures **170** and **180**. Performance and biasing of the sensor **110** may thus be improved.

FIG. **6** depicts a side view of another embodiment of a magnetic read transducer **100**". For clarity, FIG. **6** is not to scale. The read transducer **100**" may be part of a read head or may be part of a merged head that also includes a write transducer. The head of which the read transducer **100**" is a part is part of a disk drive having a media, a slider and the head coupled with the slider. The transducer **100**" corresponds to the transducer(s) **100**, **100'**, **100"** and/or **100"**. Consequently, analogous components are labeled similarly. For example, the transducer **100**" includes a read sensor **110** having free layers **112** and **116** separated by a nonmagnetic spacer layer **114** that are analogous to such structures in the transducer **100**. Thus, the components **102**, **104**, **110**, **112**, **116**, **155** and **160**" have a similar structure and function to the components **102**, **104**, **110**, **112**, **116**, **155** and **160/160'/160"**, respectively, depicted in FIGS. **2A-5B**. Further, although an ABS view is not shown, the transducer **100**" may appear substantially the same from the ABS as the transducer **100/100'**. The transducer **100**" may also include structures analogous to the structures **120**, **130**, **140** and **150** depicted in FIGS. **2A-2C**.

In the embodiment shown in FIG. **6**, the rear bias structure **160**" includes a rear bias layer **160/160'/160"** and pinning structure **190**. The rear bias layer **160/160'/160"** may be any one of a soft magnetic bias structure, a hard magnetic bias structure and a combination of soft and hard magnetic bias structures. The rear bias layer **160/160'/160"** may be a single alloy layer, a multilayer, or another structure. The rear bias layer **160/160'/160"** also has an anisotropy, as discussed above. For example, the length,  $l$ , of the rear bias layer **160/160'/160"** may be much greater than the width or height,  $t$ . In the embodiment shown, the height,  $t$ , of the rear bias layer **160/160'/160"** is shown as the same as that of the read sensor **110**. However, the heights may differ. However, the width of the rear bias layer **160/160'/160"** is the same as the track width of the sensor **110**.

In addition, the rear bias structure **160**" includes the pinning layer **190**. In some embodiments, the pinning layer **190** is an AFM, such as IrMn. For generality the depth,  $d3$ , of the pinning structure **190** is shown different from that of the rear bias layers **160/160'/160"**. However, in other embodiments, the depths may be the same. The pinning layer **190** is exchange coupled to the rear bias layer **160/160'/160"**. As a result, the pinning layer **190** may aid in

stabilizing the direction of the magnetic moment **162** of the rear bias layer **160'/160"/160'''**. For example, the pinning layer **190** may assist in returning the magnetic moment **162** to the desired direction shown in FIG. **6** in the event of a reversal.

The magnetic transducer **100''''** shares the benefits of the magnetic transducer(s) **100**, **100'**, **100''** and/or **100'''**. Performance and biasing of the sensor **110** may thus be improved.

FIG. **7** depicts a side view of another embodiment of a magnetic read transducer **100''''**. For clarity, FIG. **7** is not to scale. The read transducer **100''''** may be part of a read head or may be part of a merged head that also includes a write transducer. The head of which the read transducer **100''''** is a part is part of a disk drive having a media, a slider and the head coupled with the slider. The transducer **100** corresponds to the transducer(s) **100**, **100'**, **100''**, **100'''** and/or **100''''**. Consequently, analogous components are labeled similarly. For example, the transducer **100''''** includes a read sensor **110** having free layers **112** and **116** separated by a nonmagnetic spacer layer **114** that are analogous to such structures in the transducer **100**. Thus, the components **102**, **104**, **110**, **112**, **116**, **155** and **160'/160"/160'''**, respectively, depicted in FIGS. **2A-6**. Further, although an ABS view is not shown, the transducer **100''''** may appear substantially the same from the ABS as the transducer **100**. The transducer **100''''** may also include structures analogous to the structures **120**, **130**, **140** and **150** depicted in FIGS. **2A-2C**.

In the embodiment shown in FIG. **7**, the rear bias structure **160''''** includes a rear bias layer **160'/160"/160'''** and pinning structure **190'**. The rear bias layer **160'/160"/160'''** may be any one of a soft magnetic bias structure, a hard magnetic bias structure and a combination of soft and hard magnetic bias structures. The rear bias layer **160'/160"/160'''** may be a single alloy layer, a multilayer, or another structure. The rear bias layer **160'/160"/160'''** also has an anisotropy, as discussed above. For example, the length, *l*, of the rear bias layer **160'/160"/160'''** may be much greater than the width or height, *t*. In the embodiment shown, the height, *t*, of the rear bias layer **160'/160"/160'''** is shown as the same as that of the read sensor **110**. However, the heights may differ. However, the width of the rear bias layer **160'/160"/160'''** is the same as the track width of the sensor **110**.

In addition, the rear bias structure **160''''** includes the pinning layer **190'**. The pinning layer **190'** is analogous to the pinning layer **190**. However, the pinning layer **190'** is below the rear bias layer **160'/160"/160'''**. Thus, the region behind the read sensor **110** may be overmilled. In some embodiments, the pinning layer **190'** is an AFM, such as IrMn. The pinning layer **190'** is exchange coupled to the rear bias layer **160'/160"/160'''**. Depth, *l*, of the pinning structure **190** is shown as the same as that of the rear bias layers **160'/160"/160'''**. However, in other embodiments, the depths may be different. As a result, the pinning layer **190'** may aid in stabilizing the direction of the magnetic moment **162** of the rear bias layer **160'/160"/160'''**. For example, the pinning layer **190'** may assist in returning the magnetic moment **162** to the desired direction shown in FIG. **7** in the event of a reversal.

The magnetic transducer **100''''** shares the benefits of the magnetic transducer(s) **100**, **100'**, **100''**, **100'''** and/or **100''''**. Performance and biasing of the sensor **110** may thus be improved.

The magnetic transducers **100**, **100'**, **100''**, **100'''**, **100''''** and **100''''** have been shown with various configurations to highlight particular features, such as differences in geom-

etries. One of ordinary skill in the art will readily recognize that two or more of these features may be combined in various manners consistent with the method and system described herein that are not explicitly depicted in the drawings.

FIG. **8** is an exemplary embodiment of a method **200** for providing a read transducer. For simplicity, some steps may be omitted, interleaved, combined, have multiple substeps and/or performed in another order unless otherwise specified. The method **200** is described in the context of providing a magnetic recording disk drive and transducer **100**. However, the method **200** may be used in fabricating the transducer **100'**, **100''**, **100'''**, **100''''** and/or **100''''**. The method **200** may be used to fabricate multiple magnetic read heads at substantially the same time. The method **200** may also be used to fabricate other magnetic recording transducers. The method **200** is also described in the context of particular layers. A particular layer may include multiple materials and/or multiple sub-layers. The method **200** is described in the context of a disk drive. However, the method may be used in other applications employing a magnetoresistive and bias structures. The method **200** also may start after formation of other portions of the magnetic recording transducer.

The read sensor **110** is provided, via step **202**. Step **202** may include depositing a stack of layers for the read sensor and defining the read sensor in the cross-track and stripe height directions. Further, the shield **102** and insulating layer **106** may also be provided. The rear bias structure **160** is provided, via step **204**. Step **204** may be performed after the sensor **110** has been defined in at least the stripe height direction. Thus, at least part of step **204** is performed after at least part of step **202**. Steps **202** and **204** also include defining the read sensor **110** and rear magnetic bias structure **160** in the track width direction such that the track width of the read sensor **110** and width of the rear magnetic bias structure **160** are the same. In some embodiments, the track width of the read sensor **110** and the width of the rear magnetic bias structure **160** are defined together.

The side bias structures **120** are provided, via step **206**. Step **206** is performed after the read sensor is defined in the cross-track direction in step **202**. Thus, at least part of step **202** is performed before step **204**. Step **204** may include depositing the insulating layer **106**, depositing the material(s) for the magnetic bias structures **130** and **170**. A mill step and planarization, such as a chemical mechanical planarization (CMP) may also be performed.

Using the method **200**, the transducers **100**, **100'**, **100''**, **100'''**, **100''''** and/or **100''''** may be fabricated. Thus, the benefits of one or more of the transducers **100**, **100'**, **100''**, **100'''**, **100''''** and/or **100''''** may be achieved. Consequently, biasing of the free layers **112** and **116** in the read sensor **110** may be improved.

FIG. **9** is an exemplary embodiment of a method **210** for providing a rear bias structure of a read transducer. For simplicity, some steps may be omitted, interleaved, combined, have multiple substeps and/or performed in another order unless otherwise specified. The method **210** is described in the context of providing a magnetic recording disk drive and transducer **100**. However, the method **210** may be used in fabricating the transducer **100'**, **100''**, **100'''**, **100''''** and/or **100''''**. The method **210** may be used to fabricate multiple magnetic read heads at substantially the same time. The method **210** may also be used to fabricate other magnetic recording transducers. The method **210** is also described in the context of particular layers. A particular layer may include multiple materials and/or multiple sub-layers. The method **210** is described in the context of a disk

## 11

drive. However, the method may be used in other applications employing a magnetoresistive and bias structures. The method 210 also may start after formation of other portions of the magnetic recording transducer.

The read sensor stack is deposited, via step 212. Step 212 includes depositing the free layer 112, depositing the non-magnetic layer 114 and depositing the free layer 116. The read sensor 110 is defined in the stripe height direction, via step 214. In some embodiments, step 214 occurs before the read sensor is defined in the cross-track direction. Step 214 may include masking and ion milling the read sensor stack. Thus, space may be made for the rear bias structure 160/160'/160"/160'''/160''''/160'''''. The insulating layer 155 is provided, via step 216. The pinning layer 190/190' may optionally be provided, via step 218.

The rear bias structure 160 is deposited, via step 220. Step 220 may include depositing one or more layer(s) for the rear bias structure 160. Step 220 may, for example, include depositing soft magnetic layer(s), hard magnetic layer(s) or both.

The rear soft bias structure 160 and the read sensor 110 may be defined in the cross track direction, via step 222. Thus, the rear soft bias structure 160 and the read sensor 110 are self-aligned and have matching track width/width.

An insulating layer 106 may be provided, via step 224. The side bias structures 120 may then be provided, via step 226.

Thus, the magnetic transducer 100 may be fabricated. The method 220 may also be used to fabricate the transducer(s) 100', 100'', 100''', 100'''' and/or 100'''''. Thus, the benefits of one or more of the transducers 100, 100', 100'', 100''', 100'''' and/or 100'''''' may be achieved. Consequently, biasing of the free layers 112 and 116 in the read sensor 110 may be improved.

We claim:

1. A magnetic read apparatus having an air-bearing surface (ABS) comprising:

a read sensor including a first free layer, a spacer layer, and a second free layer, the spacer layer being non-magnetic and residing between the first free layer and the second free layer, the read sensor having a rear surface opposite to the ABS, at least one side and a track width in a cross track direction parallel to the ABS; and

a rear magnetic bias structure configured to magnetically bias the read sensor in a stripe height direction perpendicular to the ABS, the read sensor being between the ABS and the rear magnetic bias structure, the rear magnetic bias structure having a width in the cross track direction and a length in the stripe height direction, the length being greater than the width, the width of the rear magnetic bias structure being substantially equal to the track width of the read sensor;

wherein the rear magnetic bias structure has a saturation magnetization-thickness product of at least one and not more than three milli-emu/cm<sup>2</sup>.

2. The magnetic read apparatus of claim 1 wherein the rear magnetic bias structure has a reversal field of at least one thousand Oersted.

3. The magnetic read apparatus of claim 2 wherein the reversal field is at least five thousand Oersted.

4. The magnetic read apparatus of claim 2 wherein the track width is not more than twenty nanometers.

5. The magnetic read apparatus of claim 2 wherein the length is at least four multiplied by the width.

6. The magnetic read apparatus of claim 5 wherein the length is at least ten multiplied by the width.

## 12

7. The magnetic read apparatus of claim 1 wherein the read sensor has a track width of not more than thirty nanometers.

8. The magnetic read apparatus of claim 1 wherein the rear magnetic bias structure includes at least one of a rear soft magnetic bias structure and a rear hard magnetic bias structure, the rear hard magnetic bias structure having a hard bias coercivity of greater than one hundred Oersted, the rear soft bias structure having a soft bias coercivity of less than one hundred Oersted, wherein the magnetic read apparatus further includes:

an insulating layer between the read sensor and the rear magnetic bias structure.

9. The magnetic read apparatus of claim 8 wherein the hard bias coercivity is greater than one thousand Oersted and the soft bias coercivity is less than ten Oersted.

10. The magnetic read apparatus of claim 8 wherein the rear magnetic bias structure includes:

a pinning layer coupled to the at least one of the rear hard bias structure and the rear soft bias structure.

11. The magnetic read apparatus of claim 1 wherein the rear magnetic bias structure is configured to magnetically bias the first free layer and the second free layer in a scissor mode, the magnetic read apparatus further including:

a side bias structure adjacent to the at least one side, the side bias structure being configured to magnetically bias the first free layer and the second free layer to be antiferromagnetically aligned.

12. A disk drive comprising:

at least one medium; and

at least one slider including at least one magnetic transducer having an air-bearing surface (ABS) configured to reside in proximity to the at least one medium during use, the at least one magnetic transducer including a read sensor and a rear magnetic bias structure, the read sensor including a first free layer, a spacer layer, and a second free layer, the spacer layer being nonmagnetic and residing between the first free layer and the second free layer, the read sensor having a rear surface opposite to the ABS, at least one side and a track width in a cross track direction parallel to the ABS, the rear magnetic bias structure being configured to provide a magnetic bias to the read sensor in a stripe height direction perpendicular to the ABS, the read sensor being between the ABS and the rear magnetic bias structure, the rear magnetic bias structure having a width in the cross track direction and a length in the stripe height direction, the length being greater than the width, the width of the rear magnetic bias structure being substantially equal to the track width of the read sensor;

wherein the rear magnetic bias structure has a saturation magnetization-thickness product of at least one and not more than three milli-emu/cm<sup>2</sup>.

13. A method for providing a magnetic read apparatus having an air-bearing surface (ABS) comprising:

providing a read sensor stack for a read sensor, the read sensor stack including a first free layer, a spacer layer, and a second free layer, the spacer layer being non-magnetic and residing between the first free layer and the second free layer;

defining the read sensor in a stripe height direction from the read sensor stack such that the read sensor has a rear surface opposite to the ABS;

depositing a rear magnetic bias structure stack for a rear magnetic bias structure after the step of defining the read sensor in the stripe height direction, the rear

**13**

magnetic bias structure configured to magnetically bias the read sensor in the stripe height direction, the read sensor being between the ABS and the rear magnetic bias structure; and

defining a track width of the read sensor in a cross track direction and a width of the rear magnetic bias structure the cross track direction, the cross track direction being parallel to the ABS, the width of the rear magnetic bias structure being substantially equal to the track width of the read sensor;

wherein the rear magnetic bias structure has a saturation magnetization-thickness product of at least one and not more than three milli-emu/cm<sup>2</sup>.

**14.** The method of claim **13** wherein the step of defining the track width and the width further includes:

providing a mask covering a portion of the read sensor stack and a portion of the rear magnetic bias structure stack; and

performing an ion mill, the ion mill removing an exposed portion of the read sensor stack and an exposed portion of the rear magnetic bias structure stack.

**14**

**15.** The method of claim **13** wherein the rear magnetic bias structure has a reversal field of at least one thousand Oersted.

**16.** The method of claim **13** wherein the read sensor has a track width of not more than thirty nanometers.

**17.** The method of claim **13** wherein the rear magnetic bias structure includes at least one of a rear soft magnetic bias structure and a rear hard magnetic bias structure, the rear hard magnetic bias structure having a hard bias coercivity of greater than one hundred Oersted, the rear soft bias structure having a soft bias coercivity of less than one hundred Oersted.

**18.** The method of claim **17** further comprising:

providing a pinning layer coupled to the at least one of the rear hard bias structure and the rear soft bias structure.

**19.** The method of claim **13** wherein the length is at least four multiplied by the width.

\* \* \* \* \*